DOBSON SPECTROPHOTOMETER CALIBRATION NOTES

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CONTENTS

Appendix A

Appendix B

Appendix C

Appendix D

FOREWORD

Early in 1997, Ulf Kohler, DWD Hohenpeissenberg, Germany approached me with the suggestion to write a memoir of my ozone work of the past thirty-five years. My first thought when considering this suggestion was the value such a document may have towards the Dobson community. After some discussion and deliberation, it was deemed desirable to prepare a memoir which would detail my experiences and the methodologies of adjusting and calibrating the Dobson ozone spectrophotometer.

The criteria for making optical adjustments and calibrations are well defined and documented in various publications. But it was my experience in the 1960's that there was no documentation which described the actual physical techniques of making optical adjustments, and as a result, one had to learn by trial and error. Furthermore, in more recent years, new calibration and optical adjustment methods have been developed using specialized devices but the methods and the devices have not been described and documented. Therefore, it is in this regard that I have accepted the offer to relate my experiences in order to help those in the future who may be required to maintain, adjust and calibrate the Dobson ozone spectrophotometer. My experiences relate largely to Dobson ozone work while employed at AES Canada from 1959 to 1989, but also include the shared experiences and knowledge gained from World Meteorological Organization (WMO) sponsored international intercomparisons of Dobson instruments at various world locations.

The criteria that one must follow when making optical adjustments are well understood, but from personal experience it has not always been easy to obtain the required results because the technique has not been adequately described. Therefore, in writing this document, I have found it appropriate to be fully descriptive of the methodology. Sometimes the descriptions may be too lengthy but hopefully they will be useful to those who want to adjust a Dobson ozone spectrophotometer.

One cannot progress through nearly four working decades without the support, guidance and inspiration of co-workers. In particular, I want to express my gratitude to C. L. (Carl) Mateer and R. A. (Ray) Olafson at AES Canada. Furthermore, I would be remiss if I failed to thank R. (Bob) Evans, R. D. (Bob) Grass and W. D. (Walter) Komhyr at NOAA, Boulder, USA., all of whom have given me support and expert advice over many years. Lastly, I wish to thank Ulf Kohler who thought that, by writing this document, I might contribute to the important and critical on-going program of monitoring the earth's ozone layer.

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1. INTRODUCTION

It is difficult to perform work connected with a Dobson ozone spectrophotometer without the guidance of reference literature prepared by G. M. B. Dobson. In particular, when making optical adjustments to a Dobson instrument, the principal reference source is found in Dobson (1957) [1] which has guided workers for many years. There are seventeen adjustment and calibration tests described in Dobson's reference document and it has become common practice for the spectrophotometer specialist to simply refer to these tests as "Test #1, Test #2, etc.," while being fully aware of the recognized reference source. Therefore, it is appropriate to write this document using the systematic test sequence but it is emphasized that the following text should be regarded as a supplement to the information found in Dobson (1957).

The newest Dobson instrument in operational use is D 134 built in 1994 while the oldest operational instrument is D 3 built in the early 1930's. It is of interest to know that serial numbers 20 to 29 were not assigned to any instruments. The specialist should be aware that there are three identifiable groups of Dobson instruments. The first instruments, up to about D 19, are recognizable by their grey colour but some have since been re-painted white. This early design contained a simple photocell detector which was relatively insensitive but permitted the measurement of the single-pair wavelength now identified as the C pair. The advent of the photomultiplier allowed the early instruments to be retro-fitted with the more sensitive detectors and as a result the conventional Q block and Q pointer mechanisms were developed, thus creating the capability of measuring the A, B, C and D wavelength pairs. Retro-fitting began after about 1946. As a matter of interest, Dobson 3 was retro-fitted at AES Canada in 1978. Further identification of the first group is found on the inside of the instruments since they do not contain the optical reference flats below the isolating prisms P1 and P2.

The factory production of the second group of Dobsons included the quartz blocks Q1 and Q2 and their respective Q1 and Q2 pointers. This fact is emphasized because there are significant physical differences between the Q mechanisms which were supplied for the retro-fit of the early instruments and the mechanisms which became standard equipment on the second instrument group. The Dobson specialist will find that the latter Q mechanisms are much easier to adjust. The reference flats located beneath prisms P1 and P2 became a standard feature with the second group of instruments.

The features of the third group of instruments are essentially the same as the second group but with one exception. Fused quartz optics were introduced into the third group which starts after about D 110. Fused quartz optics require the angular setting of P1 and P2 to be 39 degrees as opposed to 41 degrees for crystal quartz optics.

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[1] Dobson, G. M. B., Adjustment and Calibration of ozone spectrophotometers, in Annals of the International Geophysical Year, V, Part 1, 90-113, Pergamon Press, 1957.

2. THE USE OF SPECIALIZED TEST DEVICES

The adjustment and calibration procedures described in succeeding pages sometimes refer to the use of special test devices. These devices, some of which were fabricated at AES Canada, were designed to simplify the adjustment procedures and in recent years most of these devices have been reproduced and used by Dobson specialists in various countries. The devices are identified by the following descriptions:

2.1 Auxiliary Q Plates and Q Pointers. These devices are designed to allow optical alignment procedures to be carried out in a dark room with the top cover of the instrument removed. The mechanisms consist of a quartz plate attached to a pointer which moves over an arced scale similar to the **Q scales** on the front cover of the instrument. The devices are clamped to the front edge of the instrument base on each side of the optical wedge carrier and essentially are substitutes for the **Q1** and **Q2 mechanisms** located in the top cover of the instrument.

2.2 Traverse Lamp System. This is a device which allows a Mercury lamp or a Quartz Halogen lamp to be positioned at a certain distance directly above the entrance window of the spectrophotometer. The lamp is mounted on a traverse mechanism which can be moved at small precise intervals along the length of the instrument, (i.e. across the entrance slit **S1**). The use of this device pertains to Test #10 but in more recent years has been used in a new procedure developed for Test #3.

2.3 Slit Parallelism Device. The device is used with the Mercury Lamp to test the parallelism of slit **S2** to the entrance slit **S1**. The test is not found in Dobson (1957) but was developed by Komhyr and Grass in preparation for the 1977 WMO Intercomparison at Boulder, USA. The procedure requires blocking two-thirds (left side) of **S2** to allow the Hg Test to be made through the one-third open right side of **S2.** The process is then reversed by repeating the test with the two-thirds (right side) of **S2** blocked and making the test through the one-third open left side of **S2.** In 1977 at Boulder, tape was used to mask the slit and this necessitated frequent removal of the instrument cover and the optical wedge assembly in order to re-position the masking tape. The parallelism device fits on the slit plate assembly and contains a moveable masking shutter controlled by a remote release cable, thus simplifying the procedure of blocking off parts of the slit.

2.4 Prism Setting Templates. These devices are used to position prisms **P1** and **P2** to their correct angular settings defined in Test #2, specifically 41.0 degrees for crystal quartz optics and 39.0 degrees for fused quartz optics. The base of the template sits on the machined reference flats below the prism and the angled surface interfaces with the prism surface. The template may be constructed of a suitable substance (about 5 mm thickness) which gives a smooth machined surface, such as aluminum or teflon.

2.5 Traversing Microscope. Such a device is commercially available and is used for the measurement of slit widths with reference to Test #5. The device must be capable of 0.001 mm measurement precision.

3. SPECTROPHOTOMETER LAMP TESTS

3.1 Lamp Tests associated with Operational Instruments

It is accepted practice that the performance of operational spectrophotometers be checked on a regular basis using the **Mercury Lamp Test** (Hg) and the **Standard Lamp Test (**SL). The Hg lamp test identifies optical alignment changes which may necessitate adjustment to the wavelength setting **Table of Q1.** The SL test checks the stability of the instrument's **calibration level** which, essentially, refers to the **extra-terrestrial constant** given to the instrument at the time of the most recent calibration transfer from a reference instrument. It is normal practice to derive **standard lamp corrections (SLC's)** as a result of the SL test, but not all stations apply the corrections to the observed ozone data.

When a spectrophotometer exhibits stable performance, it is sufficient to perform the lamp tests **once per month.** When an instrument shows instability, **the tests should be done more often than once per month,** especially when the test results show a sudden change or whenever a continuing trend is evident in the SLC's.

It is sufficient to perform the **monthly Hg lamp test** using the line **3129 AU** which falls centrally on slit **S2** at approximately Q1 = Q2 = 84.0 degrees. Additional Hg tests may be made using the line spectra which fall on slit **S3** (3342 AU) and slit **S4** (4358 AU) but these tests are not essential when the S2 results have shown continued stability. However, it is good practice to make the Hg tests at slits S3 and S4 twice per year. **Most importantly, whenever the S2 test results show a sudden change, then the Hg tests at S3 and S4 should be made to confirm the change at S2.**

The extent of the **monthly SL test** depends upon the number of lamps which have been assigned to the instrument. Operational instruments which have **only one available lamp** are at a disadvantage because, when a change is detected, it is uncertain whether the change is due to the operation of the lamp or due to an actual change within the spectrophotometer. Therefore, operational instruments should have **a minimum of two lamps** and preferably **three or four lamps** because it is then possible to confirm that a change has occurred within the instrument by testing the additional available lamps.

The ideal monthly SL routine is to test **two lamps** and derive the **SLC** based upon the mean of both lamps. When more than two lamps are available, the extra lamps should be tested **twice per year.** Those lamps which are used for several years on a regular monthly basis will undergo a slow ageing process which may change the lamp characteristics. It is important to identify the changes of a frequently used lamp by making comparisons with less frequently used lamps.

In past years, the need to perform the **SLT** and derive **SLC's** on a monthly basis has often been questioned. However, the general consensus now exists that the monthly SLT is a very important function in identifying and maintaining the calibration status of an instrument, especially on a long-term basis when an instrument is referenced against a standard spectrophotometer at intervals of four or five years.

3.2 Lamp Tests associated with Instruments Under Re-calibration

An instrument under re-calibration is usually regarded as one which is in the process of being standardized and which possibly undergoes one or more procedures such as optical adjustments, optical cleaning, optical wedge calibration and intercomparison against a reference spectrophotometer. Regardless of the amount of work to be done in the re-calibration process, it is strongly suggested that certain fundamental lamp tests be performed **immediately before** the work begins and **immediately after** the work ends, as follows:

Hg Lamp Tests

(1) Determine **Q1 S2** and **Q2 S2** using the Hg line 3129 AU.
(2) Determine **Q1 S3** and **Q2 S3** using the Hg line 3342 AU.
(3) Determine **Q1 S4** and **Q2 S4** using the Hg line 4358 AU.

Instrument configuration for making the Hg test at slit S3 using the line 3342 AU is as follows:

* Set R-dial to zero, this allows light to pass through the optical wedge and reach S3

* Set the **long/short** lever to 'long', this blocks the S2 light and allows S3 light to pass

* Set the **clear/opaque** lever to 'opaque', this ensures that S4 light is blocked

* Reverse the signal cables at the galvanometer to obtain positive meter deflections

Instrument configuration for making the Hg test at slit S4 using the line 4358 AU is as follows:

* Set R-dial at 300, this prevents light from passing beyond the optical wedge

* Set the **long/short** lever to 'long', this allows light to pass beyond **slit S4**

* Set the **clear/opaque** lever to 'clear', this allows light to pass beyond **slit S4**

***** Remove the **mechanical Q1 and Q2 stops** at the top of the Q1 and Q2 scales. This allows the Q pointers to be moved to the low Q-values when finding the half-power point deflections on the galvanometer

SL Tests

Perform the normal standard lamp test using **all available lamps** which have been assigned to the spectrophotometer. Under certain circumstances such as exists at an intercomparison of Dobson instruments, there are usually three or four **Universal Standard Lamps** which accompany the reference Dobson instrument. It is normal that these universal lamps be tested on each instrument when the re-calibration process of the instrument has been completed. The process of using universal reference lamps has historical significance and becomes an important part of maintaining the instrument calibration on a long-term basis.

4. ADJUSTMENT AND CALIBRATION PROCEDURES

The specialist who has had minimal experience in making optical adjustments to a Dobson spectrophotometer must recognize the importance of certain details and procedures. For instance:

***** Before making adjustments to a Dobson spectrophotometer the specialist must examine any available historical record of the instrument. From the middle of the 1970's and onwards, many of the world's operational Dobson spectrophotometers have undergone a standardization process which subjected each instrument to several of the adjustment and calibration tests found in Dobson (1957). The results of the standardization process are well documented and form an important part of the history of each instrument. The specialist must become familiar with these historical records.

***** Before making an adjustment to any optical component, make **scribe marks** on the bracket which holds the optical component and on the long frame of the Dobson immediately adjacent to the bracket. This procedure is important because it allows the specialist to re-set the component reasonably close to the original position if problems arise.

***** When making any **optical alignment or adjustment,** it is advisable to perform the HG lamp test **before** the adjustment is made and **after** the adjustment is finished. This allows the specialist to qualify and quantify the effect of the adjustment. In the case of making adjustments to slit widths and separations (Test 5) it may be necessary to perform HG tests at S2 (3129 AU), at S3 (3342 AU) and at S4 (4358 AU).

***** The adjustment or re-setting of any optical component should only be done after careful consideration since some adjustments will change the existing instrument calibration. For example, **changing the angular setting of prism P1 will alter the dispersion, thus changing the absolute calibration of the instrument.** If there is any doubt about the process then advice should be obtained from a specialist.

***** The **best location** to perform optical adjustments exists at the site of a WMO sponsored intercomparison of Dobson instruments where specialists are available to give appropriate advice.

***** The **proper time** to make adjustments at an intercomparison is **after** the instrument in question has first been **satisfactorily compared** with a **reference instrument**. The adjustments should only be made with the approval of the scientific advisor in charge of the intercomparison. If the above procedure is followed in the suggested sequence then it means that the instrument's existing calibration has been correctly terminated. A new instrument calibration period may now begin **after** the optical adjustments have been made and **after** the instrument has again been inter-compared with a **reference instrument.**

4.1 Test 1 Setting of Q1 and Q2 Pointers Relative to Plane of Quartz Plates

The criterion for setting the pointers is precisely defined. When the Q1 and Q2 blocks are vertical to the plane of the machined base of the top cover, the Q1 and Q2 pointers must read 84.0 degrees. An easy method of checking the pointer settings is to invert the top cover of the Dobson on a work bench with the front of the cover facing outwards to allow the specialist to read the Q pointers, then proceed as below.

***** Place a thick piece of glass (or suitable rigid substance with a smooth surface) across the machined surface of the top cover in the area of the Q blocks.

***** It is suggested that the glass be clamped or firmly taped to the top cover to prevent movement since this will facilitate the process if only one specialist is involved.

***** Position a good quality 'L square' on the glass with the long arm of the 'L' pointing downwards facing the Q block.

***** Position the Q lever near 84 degrees since this is where it is expected to be. Using one hand, carefully bring the long arm of the 'L square' into contact with the face of the Q block. With the other hand, move the Q lever very slightly back and forth while pushing the arm of the 'L square' against the face of the Q block.

***** When the arm of the 'L square' is in full surface contact with the Q block, the Q lever should read 84.0 degrees. If the Q pointer does not indicate 84.0 degrees then it is necessary to adjust the Q mechanisms. The adjustment procedure differs between the older and newer instruments.

Older Dobson Instruments. The older instruments are retro-fitted with mechanisms which contain a fixed and positive (non-adjustable) connection between the Q pointer on the outside of the instrument and the shaft on the inside of the instrument which holds the Q block. The method of positioning and re-setting the Q block involves a double locking nut mechanism located between the end of the shaft and the Q block. Loosen the locking nut mechanism very slightly, then re-set the Q block and Q lever to the required positions using the 'L square' method, then re-tighten the locking nuts. The procedure is best achieved by two specialists since it is difficult for one person to tighten the locking nut without disturbing the critical positioning of the mechanism and it may require several attempts to achieve success.

Newer Dobson Instruments. The newer instruments were made with the conventional Q1 and Q2 mechanisms and are easily identified since they have circular plates at the centres of the Q mechanisms on the outside of the instrument. The plates, which must be removed to make the adjustments, are held by three machine screws. Removing the plates exposes another set of three screws which hold a pressure plate attached to the Q pointer arm. The pressure plate system is a substitute for the double locking nut system described for the older instruments. Loosen the pressure plate screws by

about one full turn and this should be sufficient to allow the Q block and the Q pointer to be re-set to the required position, then re-tighten the pressure plate screws.
N.B. Re-check the settings after all the screws have been tightened.

4.2 Test 2. Location of Optical Parts

The principal objective of this test is to set the isolating prisms **P1** and **P2** to the correct angular settings of **41.0** degrees (crystal quartz optics) or **39.0** degrees (fused quartz optics) with respect to the horizontal plane defined by the machined reference surfaces beneath the prisms. The task is relatively easy to perform with those instruments containing the reference flats beneath the prisms, but becomes more difficult with the older instruments which do not have the reference flats.

Dobson Instruments with Reference Flats beneath P1 and P2. One needs to have a **prism setting template ,** either 41.0 or 39.0 degrees, which is placed on the reference flat below the prism. The angled face of the template is then brought into contact with the front surface of the prism. The prism is correctly set when the sloping 41(or 39) degree angle of the template is in full surface contact with the face of the prism while the base of the template rests fully on the reference flats. A very poorly positioned prism is easy to identify by **visual inspection** using a lamp to illuminate the front of the optics in the area of the prism. If there is any uncertainty about the prism setting then a feeler gauge of 0.05 mm thickness or less may be used to test for any possible separation between the template and the prism face.

To re-set a prism, loosen the three bolts which hold the prism bracket on the long centre frame of the instrument. Loosen the bolts **just sufficiently** to allow the bracket to be rotated by the fingers, otherwise if the bracket is too loose it may create problems when tightening the bolts after re-setting the prism. Push the template against the face of the prism and make sure that contact is made over the full edge of the prism. Then, very carefully **tighten each bolt consecutively by a small amount.** Re-check the accuracy of the template and repeat the consecutive tightening process until the bolts are fully tightened then make a final check of the prism setting using the template.

Dobson Instruments without Reference Flats beneath P1 and P2. The surfaces beneath the prisms may appear to be smooth and flat but the setting of the prisms with the template should only be regarded as approximate fixations. However, there are some options which may exist with respect to setting or re-setting the prisms of older Dobsons and the specialist should consider **all of the following possibilities** before making any adjustments.

The 41.0 degree angular setting of P1 (39.0 for fused quartz optics) represents the position of **minimum deviation at 3129 A.U.** Therefore, it is possible to find a satisfactory setting of P1 by searching for minimum deviation. The process requires making a series of HG lamp tests through slit S2 while changing the angular setting of P1 at small intervals. The best method is to do an initial HG test at the original undisturbed position of P1. Next, make scribe marks on the prism bracket and the Dobson frame to establish an identifiable reference pertaining to the original undisturbed position of the prism. Loosen the prism bracket bolts by a small amount, just sufficient to allow rotation of the bracket by finger pressure. Rotate the bracket by about 1 degree, either clockwise (c/w) or counter-clockwise (cc/w) from the original undisturbed position and this becomes the start position for the series of HG tests. Make the HG tests at small intervals from the start position, passing through the original position and ending with a test about 1 degree beyond the original position. The **mean Q1** values will show a trend which will reverse direction at the point of minimum deviation.

If the calibration history of the spectrophotometer is well documented and the instrument has been in satisfactory operational use for several years, then it may be advisable **to accept the existing angular settings of P1 and P2.** For instance, with reference to **Test 5,** if the widths of slits **S2** and **S3** are within specifications and the centre to centre separation (S2 to S3) agrees within **+/- 0.15 mm** of the suggested "approximate" value of **7.45 mm,** then it strongly suggests that the angular setting of **P1** is satisfactory. It is difficult to define a period of satisfactory operational use but in general it means that the instrument does not exhibit a "mu dependence" when compared with a reference instrument. Furthermore, the instrument has participated in two or more inter-comparisons, usually separated by four years, and has not required critical adjustments to the extra-terrestrial constants (ETC's) after the first inter-comparison against a reference instrument.

4.3 Test 3. Setting Lenses L1 and L2 to Correct Focus

The method described in Dobson (1957) is lengthy and tedious requiring the use of photographic plates and the need to frequently remove the top cover of the instrument. In addition, slit S1 must be set to a very narrow width thus creating the difficulty of re-setting the slit to its original precise width after L1 has been correctly focused.

An alternate method was developed at AES Canada (circa 1978) and, by comparison, has proven to be equally precise. The new method is easier to preform since it does not require the use of photographic plates or the need to narrow the width of S1 and it is not necessary to frequently remove the instrument cover. The alternate test methodology and a description of the test device is found in Appendix A.

4.31 Test 3.1 Horizontal Alignment Test

This test, not found in Dobson (1957), was developed in the 1960's and became a required test in the mid 1970's as part of the WMO Dobson standardization program. The test examines the optical path with respect to the manner in which **mirror M1** reflects the **image** of **S1** onto the plane defined by **S2, S3** and **S4** and, subsequently, how **mirror M2** reflects the images of S2, S3 and S4 onto the face of the photomultiplier box at S5**. The test ensures that the slits S2, S3, S4 and S5 are being uniformly illuminated in the horizontal axis.** When the test results are not satisfactory, corrective procedures are made by placing shims between the mirror mounts and the mirror brackets. Tests are done on both the Q1 and Q2 sides of the instrument.

When the horizontal alignment test was developed in the 1960's, the Q1 side of the instrument was tested by placing a **photographic plate** in the horizontal plane at S2. A reference mark on the photographic plate represented the horizontal centre of S2. The positions of the photographic images of Hg lines 3126 and 3131 AU were examined with respect to the reference mark on the plate and this determined whether or not mirror M1 needed to be adjusted by shims. The Q2 side of the instrument was similarly checked by placing a photographic plate at slit S5.

An Alternate Test Method developed in the 1970's uses the **Auxiliary Q Blocks and Q Pointers** which are positioned on the instrument **with the top cover removed** and with the Hg lamp positioned above slit S1. When the laboratory is darkened and the Q1 pointer is set near 48 degrees, it is possible to see the visible blue/green image of S1 near the plane of S4 created by the Hg line 4358 AU. If the visible image of S1 is not on the horizontal centre of S4 then mirror M1 must be adjusted with shims. Similarly, the Q2 side of the instrument may be tested by checking where the visible blue/green image of slit S4 falls near the plane of slit S5.

Before removing the top cover of the instrument, perform the Hg Lamp Test at slit S4 using line 4358 AU. (See para. 3.2 for the S4 test configuration) The purpose of this test is to establish the Q1 and Q2 values which are needed later on when setting the auxiliary Q1 and Q2 pointers for the alternate test method.

To check the Q1 side of the instrument using the Alternate Method, proceed as follows:

* Remove the top cover from the Dobson.

* Place the Hg lamp, without the GQP, on top of the inlet window tube and tape the lamp firmly to the inlet tube. (The inlet window tube is that which houses slit S1).

* Remove the optical wedge bridge assembly and attach strips of **white cardboard** (or stiff white paper) about 8 mm wide on the left and right edges of the **slit S4** achromatising lens bracket, (this is the lens through which the light passes before reaching S4). **The strips of cardboard should block out about 2 to 3 mm of S4 on both the left and right edges of the slit. Make horizontal marks (with a pencil) on both pieces of the white cardboard immediately adjacent to the vertical centre of slit S4.**

* Restore the optical wedge bridge assembly to its normal position.

* Place the auxiliary Q1 Block and Q1 Pointer on the instrument.

* Set the auxiliary **Q1 pointer to the mean Q1 S4 value** found above and this will bring the **Hg line 4358 AU** to a focus near the plane of **S4.** Darken the room to a low light level (but not fully dark) and allow the eyes to acclimatize.

* Place a piece of white paper (size about 8 x 8 cm.) in a **vertical position about 12 to 16 cm to the right of S4,** directly in the optical path between L1 and S4. Make sure that the top of the paper does not obstruct the optical path between the Q1 block and lens L1. A blue/green image of S1 (slightly out of focus) should be visible on the white paper. If not, then slowly adjust the Q1 pointer, either up or down, by a few degrees, until the colours are visible on the paper about 4 to 6 centimetres from the bottom of the paper. **Remove the white paper,** thus allowing the colours to fall near S4**.**

* **View the illuminated area of S4 by looking with the eyes positioned just behind mirror M1.** The blue/green colours should be visible on the strips of white cardboard on both sides of slit S4 and should be in reasonably good focus. If necessary, adjust the Q1 pointer so that the colours fall near the pencil marks on the cardboard. The less experienced specialist may have some difficulty in identifying these colours and should change the eye level to just below or to the left of lens L1. In addition, the **reflections from the surfaces of the achromatising lens** on the right-hand side of S4 may cause some difficulty and confusion.

* **The Q1 side of the instrument is in good horizontal alignment when the strips of cardboard on both sides of S4 are equally illuminated in the horizontal.** If one strip is significantly illuminated more than the other then it will be necessary to place shims in the mirror M1 assembly. **Shimming a mirror is not a difficult process,** especially when using the alternate method as described above, since it possible to see the immediate results without having to use photographic plates.

***** The mirror assembly comprises a **mounting bracket** attached to the long centre optical frame of the instrument. A **circular housing** in which the mirror is mounted is attached to the mounting bracket by **three machine bolts**. With reference to a 360 degree circle, viewed from behind mirror M1, **the bolts are located at 45, 135 and 270 degrees.** The shimming process requires placing shim material on the bolts between the mounting bracket and the circular housing.

* If the horizontal illumination of the white cardboard is more pronounced on the **left side of S4** than on the right side, then it is necessary to place a shim on **the 270 degree machine bolt.** If the illumination is more pronounced on the **right side of S4** then it is necessary to place shims at either the **45 or 135 degree bolts, or both.**

* Shimming materials should be metallic with a thickness of 0.05 mm. or greater. One of the best materials is **aluminum foil** (used in food processing packaging) which is very thin but can be easily used in multiple layers to create any desired shim thickness. Each shim must have a hole punched in the centre which allows the machine bolt to pass through.

* When placing a shim on any mirror, first loosen all of the machine bolts by two to three revolutions, then totally remove the bolt on which the shim is to be placed. Using a set of tweezers (or other device), place the shim between the mounting bracket and the circular mirror housing while aligning the hole in the shim with the threaded holes in the bracket and mirror housing. **Re-insert the machine bolt and tighten all three bolts.**

- Re-check the illumination of the white cardboard on both sides of S4 and, if necessary, repeat the shimming process until the cardboard is equally illuminated on both sides.

To check the horizontal alignment of the Q2 side of the instrument, it is necessary to ensure that the light reaching slit S4 is allowed to travel without interference from S4 to the entrance of the photomultiplier box at S5. Proceed as follows:

- Do not disturb the auxiliary Q1 block and Q1 pointer since it is necessary to use the light falling on slit S4 to check the Q2 side of the instrument.

- Remove the optical wedge bridge assembly and detach the white cardboard strips from the edges of S4. Replace the assembly.

- Place the cardboard strips on the edges of slit S5 making sure that the strips block out equal amounts on the right and left edges of the slit.

- Using the fingers, **move the rotating sector wheel** so that the **S4 gap** in the sector wheel is in front of S4. This allows the S4 beam to pass to the Q2 side.

- Place the **long/short** wavelength selector lever to the **'long'** position, (push the lever in as far as it will go). This allows the S4 beam to pass to the Q2 side.

- Place the **clear/opaque** lever to the '**clear'** position. This allows the S4 beam to reach lens **L2,** prism **P2** , mirror **M2** and slit **S5.**

- **Darken the room,** then look from behind mirror M2 towards S4, it should be possible to see the blue/green colours of the Hg line 4358 AU at S4. If the colours are not visible it may be necessary to make small adjustments to the angular setting of the auxiliary Q1 pointer.

- Set the auxiliary Q2 pointer to the **mean Q2 S4 value** found in the preliminary test.

- When the colours are visible at S4, then it should be possible to see the image of S4 in the Q2 auxiliary quartz block. Also, it should be possible to see the colours on the white cardboard strips at the edges of S5 but it may be necessary to adjust the angular setting of the Q2 pointer to achieve best results.

- The strips of white cardboard on the edges of S5 must be **equally illuminated**, otherwise it will be necessary to place shims on the bolts of mirror M2.

A Word of Caution. Difficulty is sometimes experienced when trying to locate the blue/green colours at the auxiliary Q2 block and at S5. When this happens it is suggested to hold a strip of white paper (5 cm wide) near the achromatising lens on the left side of S4 to determine whether or not the light beam has reached that position. If the colours are not visible at that point then the beam is probably being obstructed in the direction backwards towards S4. Re-check the position of the

rotating sector wheel to verify that the **S4 gap** is correctly positioned**,** also the **long/short lever** is at the **'long'** position and the **clear/opaque** lever is at the **'clear'** position. When the colours have been located at the achromatising lens, then it should be possible to see the colours at the Q2 block and at slit S5. **It is not possible to see the colours near lens L2 because the beam has become very diffuse at that point.** If the colours are still not visible at
S5 then it is possible that the angular setting of the S4 achromatising lens on the Q2 side is not correct.

4.4 Test 4. To Set Photomultiplier in Best Position Across the Instrument

The test method, described in Dobson (1957), does not specifically define what is the **'best area'** of the photo-cathode to use, but it is assumed that the **most sensitive area** is important. It is also reasonable to assume that an **area of constant sensitivity** should have equal consideration**.** The sensitivity contours of a typical multiplier, shown in Figure 4 of Dobson (1957), suggest that it may be difficult to find a suitable compromise area of the photo-cathode which would satisfy both needs. **However, the contours show that the need to position the tube across the instrument is much less critical than the need to find the best vertical position of the tube.**

The method of mounting the photomultiplier does not lend itself to making critical positioning of the tube **across the instrument** and, bearing in mind that most Dobsons now contain the more sensitive **EMI-9781 photomultiplier,** the practice of performing Test 4 has generally been discontinued.

4.41 Technical Discussion Number 1

It is often assumed that a spectrophotometer is correctly adjusted and calibrated whenever **Tests 1 to 17** are completed in numerical sequence, however, **experience has shown this to be an incorrect assumption.**

During the optical alignment process, the specialist should make a habit of re-checking certain tests, in particular the **Hg tests of Q1 S2, Q1 S3, Q2 S2 and Q2 S3,** to ensure that the most recent optical adjustments have not changed the results of earlier tests which were previously found to be satisfactory.

It has also been determined that the optical adjustment process may be simplified by re-arranging the numerical order of some of the test processes. It is clearly understood that **Tests 1, 2, 3 and 4** should be completed in the suggested order, but before proceeding with **Test 5** (the setting of slits by measurement) it is strongly recommended that a **preliminary check of Test 12** be made and, if necessary, adjust **the vertical position of the photomultiplier tube.** If this procedure is not followed, it may result in the need to repeat a large amount of tedious work to satisfy the specifications of **Tests 5 and 7.**

For example, at the 1977 WMO intercomparison, Boulder, USA, during the verification of D 77 (AES Canada) it was necessary to adjust the multiplier vertical position in order to satisfy Test 12. The effect of the adjustment was to change the Hg test results of **Q1 S3** and invalidate the relationship of **S2 to S3** which had previously been within the specifications defined in Test 7. It then became necessary to adjust the height of slit S3 (Test 5) in order to satisfy the needs of Test 7.

The following numbers, obtained from tests with D 77 on July 26, 1977 at Boulder, show a series of experimental Hg tests which illustrate the effect of adjusting the height of the photomultiplier. The multiplier height values represent the distance between the reference flat on which the multiplier box is housed and the bottom of the plate on which the multiplier assembly is mounted. All Hg test Q values are reduced to 15 degrees C.

Q1 S2	**Q1 S3**	**Delta Q**	**Multiplier Height**
82.8	**81.5**	**1.3**	**1.25 mm**
82.9	**82.0**	**0.9**	**1.00 mm**
82.8	**82.2**	**0.6**	**0.75 mm**
82.8	**82.6**	**0.2**	**0.50 mm**

When the multiplier tube is systematically lowered the **Q1 S3** test values increase and the **S2-S3 relationship** correspondingly improves. The above values are representative of only one instrument, D 77, but the results clearly demonstrate that the vertical positioning of the multiplier may have a critical influence when trying to achieve a correctly adjusted instrument. Therefore, it is strongly emphasized that a preliminary check of Test 12 should be done before proceeding with Test 5. It will, of course, be necessary to re-confirm the multiplier position by repeating Test 12 at the appropriate time later on.

The specialist must understand that **Tests 5, 6 and 7** are interdependent and should be grouped together as a **composite test**. For instance, when slit **S2** has been set to the correct width it is advisable to do a preliminary check of Test 6 to confirm that **Q1 S2** reads **84.0 +/-0.5** degrees (reduced to **15 deg C)** and, if necessary, adjust the setting of **M1** in the vertical plane before proceeding with the remaining parts of Test 5.

Another important point to remember involves the setting of slit **S3.** In addition to achieving the S3 width specification (Test 5), it is also necessary to satisfy the specifications found in Test 7 with regard to the agreement between **Q1 S2** and **Q1 S3** which states that Q1 S3 shall agree within +/- 0.5 degrees of Q1 S2. Failure to achieve the +/- 0.5 degree agreement means that **S3** must be physically adjusted either upwards or downwards. A situation similar to that of slit S3 exists with the setting of slit **S4** since the Test 7 specification states that when Hg 4358 AU falls centrally on S4, then **Q1 S4** shall read **48.0** degrees +/-**2.0** degrees (Q1 reduced to 15 degree C). Therefore it may be necessary to vertically adjust S4 to satisfy the specification.

4.5 Test 5. Setting of Slits by Measurement

One of the most difficult adjustments of a Dobson spectrophotometer involves setting the slits S1, S2, S3, S4 and S5 to the specifications defined in Dobson (1957). Additional specifications were introduced at the 1977 Boulder WMO Intercomparison requiring slit S2 to be set parallel to slit S1 and that slits S3 and S4 be set parallel to slit S2. It is not difficult to measure the existing slit widths using a traversing microscope with a viewer which contains a set of cross-hairs. The difficulty arises when the existing widths are found to be outside the limits specified in Test 5, thus requiring physical adjustments to be made to the slit.

There is one basic and very important rule to remember when adjusting the width of any slit. Try to determine if one jaw of the slit is already correctly set, then adjust the other jaw to achieve the correct setting. This simple procedure may save a great deal of work. The inexperienced specialist who is attempting slit adjustments for the first time may find it difficult to determine when a slit jaw may or may not already be correctly set. But the experience of the first attempt will be very valuable for later attempts.

The first specification in Test 5 (Dobson 1957) states that slits **S1 and S5 be set to the same height above the reference plane.** This requirement is understood but the height above the reference plane is not defined. Furthermore, it is not specified which parts of the slits must be at the same height and it is important to know this detail because the widths of S1 (0.40 mm) and S5 (3.00 mm) are very different, but it is assumed that the **'vertical centres'** of each slit be set to the same height above the reference plane. The text of Test 5 (Dobson 1957) does not suggest a method of checking that S1 and S5 are at the same height above the reference plane and to the author's knowledge this requirement has been ignored.

The setting and verification of slit S1 must be done first. Do not attempt to adjust or verify the settings of slits S2, S3, S4 and S5 until after slit S1 has been correctly set since to do otherwise may create extra work later which could possibly have been avoided.

4.51 Measuring the Slits

It is normal to make width measurements at three positions along a slit. First, near the **horizontal centre** of the slit and about half-way between the centre and the **left** and **right** ends of the slit. Using a pencil, make reference marks on one of the slit jaws at the **three measuring points**. This allows measurements to be made at approximately the same place when repeat measurements are needed.

It is normal to make measurements in **both directions (Up and Down) across the slit** and to repeat the process **at least twice** at any given measuring point to obtain at least four values at that point. The mean width is calculated for each of the three measuring points and the **overall width** is then determined. The following is a typical set of S2 width values measured on Dobson #18 :

	Left of Centre	Centre	Right of Centre	
Up	0.3975	0.399	0.398	
Down	0.3985	0.3975	0.3965	
Up	0.3975	0.398	0.3985	
Down	0.398	0.399	0.3975	
Mean	**0.3979**	**0.3984**	**0.3976**	**Overall Mean = 0.3980**

When viewing slits through a microscope it is occasionally found that the edges of some jaws have been poorly machined and contain rough and jagged areas. Avoid these areas of the jaw when selecting the measuring points. In extreme cases it may be advisable to try to correct the problem. Remove the jaw then lay a piece of very fine emery cloth on a flat surface. Hold the jaw in a horizontal position and very gently stroke the jaw two or three times across the emery cloth using minimal pressure and maintaining uniform pressure along the length of the jaw. Wash the jaw with alcohol or any suitable liquid to remove any fine metal particles, then inspect the jaw under the microscope before restoring to its normal position.

4.52 Methods of Physically Adjusting Slit Widths

The text in Test 5 (Dobson 1957) does not suggest any method of making the physical adjustment to achieve the desired slit width. The adjustment method described here was developed in the 1960's and 1970's and relates to the shared experiences of several Dobson specialists at NOAA Boulder and AES Toronto. Other methods will also be outlined. Proceed as follows when a slit needs to be adjusted:-

* It is assumed that S2 is to be adjusted with width specification of **0.40 mm +/- 0.01**

* Place the slit plate assembly beneath the microscope and firmly anchor the plate with clamps to avoid movement.

* Determine which slit jaw is to be adjusted and slightly loosen the screws on both ends of the jaw by one quarter turn of the screws. **Do not overly loosen the screws.**

* Identify the **Left** and **Right** reference marks on the slit jaw since these are the positions on the jaw where the adjustments will be made.

* Adjust the microscope so that the cross-hairs are positioned on the **exact edge** of the undisturbed jaw **at the left reference mark,** then move the cross-hairs exactly 0.40 mm in the direction towards the loosened jaw.

* While viewing through the microscope, move the loosened jaw so that the edge falls exactly on the cross-hairs. The process may be done using the tip of a small screwdriver and tapping on the back-side of the loosened jaw blade.

* Using the fingertips, press firmly downwards on the slit jaw and slightly tighten the screw on the end where the width adjustment was made. **Do not completely tighten the screw at this time.**

*   Repeat the above steps at the **right side reference mark** of the jaw.

* Re-check the width measurements at the three reference marks and, if necessary, repeat the process starting from the first step. **Do not firmly tighten the screws until the slit width is correct. Re-check the width after the final tightening is done.**

In theory, the adjustment process described above appears to be easy but in practice it may be very difficult. The major problem arises when tightening the screws because the tightening process sometimes changes the position of the jaw and it may be necessary to repeat the left-side and right-side adjustments several times.

Each specialist develops individual techniques. One suggestion is to **barely loosen the screws**, then to adjust the slit width by placing the tip of a small screwdriver near the end of the jaw and to tap the butt end of the screwdriver with a small hammer while viewing the slit adjustment through the microscope. This method reduces the chances of changing the slit width when the final tightening of the screws is done.

An alternate method of setting slit widths has been used by specialists at the Solar and Ozone Observatory, Hradec Kralove, Czech Republic. The technique requires selected materials which have thicknesses equivalent to the widths of the various slits. The material is placed between the slit jaws which are then tightened against the material to establish the correct slit width. The method has advantages because it eliminates some of the problems of disturbing the position of the jaws when the screws are to be tightened.

In 1994, when Dobsons 131 to 134 were being built, the factory process of setting slit widths was observed at Ealing Electro Optics, Watford, UK. The technique is described as a '**shadow graph method'** which projects the image of the slit plate onto a screen. The slit plate image has been magnified (1 x 50) and falls onto a similarly magnified graphic layout of the slit plate. With this degree of magnification, it is very easy to precisely adjust the position of the slit jaws to match the magnified graphic layout on the screen. **But the problem of tightening the screws on the slit jaw still exists.**

4.53 Setting Slit S1 at 0.40 mm +/- 0.01 mm

The slit plate of S1 is mounted in a tubular assembly about 5 cm below the main entrance window and the tube must be removed in order to measure the slit width. Remove the three machine bolts which hold the base of the tube to the instrument frame. It may be difficult to separate the tube assembly from the frame because of two locating guide-pins also mounted in the frame. Gently tap on the three exposed sides of the tube then pull upwards on the tube while trying to create a rocking motion from side to side.

Position the tube on its side beneath the microscope with the slit facing upwards. Anchor the tube with tape or a clamping device since it is important to avoid any movement when attempting to measure to the required precision. Place a small light bulb near the entrance window at the end of the tube in order to illuminate the underside of the slit.

It is noted that S1 has a slightly curved shape with the lowest part of the curve at the horizontal centre of the slit.

It has been found that, with some spectrophotometers, there are inconsistencies in the shape of the curved S1 jaw blades and the specialist should not be surprised to find it may be impossible to obtain a uniform width along the horizontal length of the slit. Some examples of S1 width measurements are given below and it should be understood that the measurements and eventual adjustments, where necessary, were made by the same specialist using the same traversing microscope equipment.

S1 Widths in mm.	Left	Centre	Right	Mean	
Dobson 03	0.401	0.405	0.401	0.402	
Dobson 15	0.400	0.402	0.400	0.401	
Dobson 17	0.366	0.396	0.422	0.395	Before adjustment
Dobson 17	0.402	0.402	0.403	0.402	After adjustment
Dobson 43	0.401	0.402	0.398	0.400	
Dobson 60	0.406	0.405	0.406	0.406	
Dobson 62	0.401	0.407	0.421	0.410	
Dobson 75	0.406	0.406	0.407	0.406	
Dobson 104	0.401	0.410	0.398	0.403	
Dobson 134	0.392	0.426	0.388	0.402	

Note the measured S1 widths of D104 and D134 where It was impossible to produce a uniform width along the length of each slit because of the inconsistency in the shape of the curvature of each jaw. In the case of D134 the inconsistency was very severe and when the jaws were closed against each other there remained a space of about 0.1 mm between the top and bottom jaws near the horizontal centre of the slit. Therefore, the final width setting of S1 on D134 became a compromise based upon the **mean** of the **left, centre and right** position measurements.

If it is necessary to adjust the width of S1, then it becomes necessary to dismantle the tubular assembly in order to gain access to the slit plate. Proceed as follows:-

***** The tubular assembly contains **two small set screws** located about 3 cm from the base and on opposite sides of the tube. Loosen the two set screws by one full turn and this allows the **top section** of the assembly to be withdrawn from the **bottom section**. There is a large slotted screw on the back of the bottom section but do not disturb this screw.

* The **top section** of the assembly contains the S1 slit plate but it is necessary to dismantle the top section to gain access to the slit plate. There are **three small slotted machine screws** located at the base of the top section. One of these screws

is located at the front, immediately below the horizontal centre of the slit. The other two screws are located **120 degrees** to the left and right of the centre screw. Remove the three screws and this allows a **small assembly** (about 3 cm in depth) to be withdrawn from the base of the top section. The slit plate is located on the small assembly.

* The slit plate can be removed from the small assembly by removing **two slotted machine screws** in the base of the small assembly and it is advisable to do this because the slit plate housing has a flat surface on the back side and the flat surface makes it easier to anchor the plate when making the adjustments and measurements.

* A right-angle prism is mounted in the small assembly immediately behind the S1 plate and the prism becomes fully exposed when the slit plate is removed. It is appropriate to inspect the prism for cleanliness at this time, also to check that it is firmly attached to the assembly since, on some Dobsons, the cement has failed to hold the prism in place. The prism may be re-mounted using a small amount of epoxy cement.

It is difficult to understand the method whereby slit S1 is made parallel to the horizontal reference base of the instrument since slit S1 is curved. However, it is possible to make some measurements which will show whether or not the slit is satisfactorily positioned.

The jaws of the slit are mounted on an **L-shaped bracket** and the base of the bracket may be regarded as a reference flat. Using a traversing microscope, make measurements from the reference base to the top left and top right corners of the bottom slit jaw. The distance should be about 14 mm but the exact value is not critical. The important factor is that both distances should be equal or nearly so.

If the S1 width needs to be adjusted, it is advisable to begin by checking the parallelism of the bottom jaw as described above. If the bottom jaw is found to be parallel with the base then the width adjustment will be made by adjusting the top jaw. When a jaw of S1 has been loosened, avoid moving the jaw in a sideways direction because this will create a mismatch between the curvatures of the two jaws and make it difficult to obtain a uniform width setting along the length of the slit. (See Page 20 and the example width setting for D62).

4.54 Setting Slit S2 at 0.40 mm +/- 0.01 mm

In addition to ensuring that the slit width is correct it is also necessary to ensure that S2 is parallel to S1. The specialist must first make two measurements and tests since the results will determine the proper sequence of work when remedial action is needed. Proceed as follows:

(1) The slit parallelism test.

(2) A measurement of the S2 width at the **Left**, **Centre** and **Right** marker positions.

The slit parallelism device (see Page 5. para. 2.3) is mounted on the main slit plate attached to optical wedge bridge. Remove the top cover of the Dobson then remove the wedge bridge. The test device fits on top of the main slit plate and is held by two small set screws. Before re-inserting the wedge bridge, actuate the release cable (in and out) to ensure that the blocking shutter on the parallelism device is being properly positioned to allow the **1/3 left** and **1/3 right** of the slit to be opened. **At this time it is important to identify which side of the slit (left or right) is 1/3 open when the release cable is either 'in' or 'out. The 'left' and 'right' sides of the slit are determined by viewing the slit from the Q1 side of the instrument.** Restore the wedge bridge. Before placing the top cover onto the instrument, remove the right-side inspection lid and feed the release cable through the lid opening when the top cover is placed on the instrument. The inspection lid is placed on the top cover but cannot be fully tightened due to the release cable. Place a black cloth over the lid to prevent light leakage into the instrument. Place the Hg lamp, with the GQP, on the inlet window and allow the lamp to warm. Proceed as follows:-

* Start at either the left or right position and perform the normal Hg test (3129 AU). It is sufficient to make a series of two or three tests at the 'Q1 above' and 'Q1 below' positions provided that the results are consistent. Calculate the mean Q1 values.

* Re-position the shutter block with the release cable then repeat the above tests at the opposite end of the slit and calculate the means.

The following hypothetical mean values show, (i) a slit with both the top and bottom jaws which are perfectly parallel to S1, (ii) a slit whose top jaw is not parallel to S1, and (iii) a slit with both jaws out of parallel with S1.

	(i)		(ii)		(iii)		
	Left	Right	Left	Right	Left	Right	
Mean 'Q1 above'	80.0	80.0	80.0	80.0	80.0	79.7	Bottom Jaw Cut-off
Mean 'Q1 below'	88.0	88.0	88.0	88.4	88.0	88.4	Top Jaw Cut-off

It is noted that the smaller values (Q1above) represent the cut-off created by the **bottom jaw** of S2 while the larger values (Q1 below) represent the cut-off created by the **top jaw** of S2. It is important to remember this relationship when slit jaws are to be adjusted.

The perfectly parallel slit in example (i) shows the Left and Right Q values to be equal on both the top and bottom jaws but it is extremely difficult to achieve such results. Therefore, it is acceptable to use certain limiting criteria. Ideally, the Left and Right mean Q1 values on any jaw should agree within **0.1 degrees** but **0.2 degrees is acceptable when difficulty is experienced.** If either one or both jaws do not meet the criteria then the slit will require adjustment, but it is imperative to measure the slit width before disturbing the jaws. Refer to the text of para. 4.51 and measure the width of S2.

After the S2 parallelism test and the width measurements have been made, there are several options to be considered when deciding the possible adjustment sequence.

Some options are clearly obvious and some are less obvious but **read all of the following options (a) to (d) before making any decision.**

N.B. Lowering S2 by 0.1 mm decreases the Q1 S2 reading by 1.25 degrees of Q.

(a) When S2 is not parallel to S1, it means that S2 must be adjusted and the required adjustment depends upon the factors described in (b) or (c).

(b) If one jaw of S2 is within the parallelism criterion of 0.1 degrees of Q1, then adjust the other jaw of S2 to create the correct parallelism requirement. During this process set the jaw to create the correct slit width of 0.40 mm +/- 0.01mm.

(c) If both jaws of S2 do not meet the parallelism requirements, then select one of the jaws (it does not matter which one) and set it parallel to S1. **Do not loosen the second jaw until the first jaw has been correctly set because the undisturbed second jaw can be used as useful reference when setting the first jaw.**

(d) When (c) has been completed, then adjust the second jaw to make it parallel to S1 while setting the slit to the correct width.

After the final tightening of the slit jaws, re-measure the slit width to ensure that the jaws did not move during the tightening process.

4.55 Technical Discussion Number 2

It is assumed at this point that S2 is set to the correct width and is parallel to S1. Before proceeding to check the setting of slit S3 it is advisable to perform the Hg Test on the Q1 side of the instrument at S2 (3129 AU).

Whenever the width of S2 has been adjusted it will most likely change the physical height of the slit above the reference plane and this will automatically change the values of Q1 S2 for 3129 AU found in the existing Table of Q1 settings. If the Hg test shows that the Q1 values have changed by +/- 0.3 degrees or more from the existing table value, then it is advisable to adjust mirror M1 in the vertical plane and restore the values found in the existing Q Table. The mirror adjustment procedure is found in Test 6 and note that the tabled values given in the text of Test 6 refer to Q1 S2 values reduced to 15 deg. C.

Before proceeding further, it is strongly advised to make a preliminary check of Test 12 which deals with Setting the Photomultiplier to the Best Vertical Position. The reason for this has been described in Para. 4.41 (Technical Discussion Number 1). The preliminary check should show that a satisfactory vertical position exists with respect to slit S2. Adjust the height of the multiplier if the criterion for S2 is not satisfactory. **Do not proceed to the setting of slit S3 (para. 4.56)** until the criterion for Test 12 has been satisfied because the width and height settings of S3 are greatly influenced by the vertical height of the photomultiplier.

4.56 Setting Slit S3 at 1.20 mm +/- 0.2 mm

Begin this procedure by first making Hg tests of **Q1 S2** and **Q1 S3** to identify the existing relationship between S2 and S3 since Test 7 specifies that the respective Q values should agree within +/- **0.5 degrees.** It has already been established that S2 is correctly set, therefore, when Q1 S3 differs from Q1 S2 by more than 0.5 degrees it has then been established that slit S3 needs to be adjusted. When the respective values agree within 0.5 degrees it does not necessarily mean that S3 is correctly set because the parallelism and width of the slit are not yet known. Proceed as follows:

* Perform the slit parallelism test of S3 in the same manner as that for S2.

* Measure the width of S3 at the Left, Centre and Right positions along the slit as was done for S2.

N.B. Lowering S3 by 0.1 mm decreases Q1 S3 by 1.25 degrees.

The adjustment options for S3 are similar to those outlined for S2 except that S3 must be made parallel to S2. **The most difficult and lengthy adjustment of S3 exists when trying to satisfy the Test 7 requirement to make Q1 S3 agree within 0.5 degrees of Q1 S2.** But **t**he experienced specialist should have no difficulty in achieving the desired agreement and will often achieve an agreement of 0.2 degrees of Q.

The less experienced specialist who is making the adjustments for the first time is advised to follow a lengthy but easier method to set S3 as follows:

* Set the **top jaw of S3** at **6.65 mm +/- 0.05 mm** from the **bottom jaw of S2** and at the same time make the top jaw of S3 jaw parallel to the bottom jaw of S2.

* Then set the bottom jaw of S3 parallel to the top jaw of S3 to provide a uniform slit width of 1.20 mm (+/- 0.02 mm) along the length of the slit.

The reason for using the above method stems from the fact that when both S2 and S3 are correctly set, the distance from the centre of S2 to the centre of S3 should be approximately **7.45 mm** as specified in Dobson 1957, Test 5. Therefore, when using the value of **6.65 mm** plus half of the width of S2 (**0.20 mm**) and half of the width of S3 (**0.60 mm**), the centre to centre separation between S2 and S3 should be near 7.45 mm and the Q1 S2 to Q1 S3 relationship should be satisfactory. If it is not satisfactory, then further adjustments will be needed but it is then apparent in which direction, up or down, Slit S3 must be moved.

After the final tightening of the S3 slit jaws, re-measure the slit width to ensure that the jaws did not move during the tightening process and then perform Hg tests of Q1 S2 and Q1 S3 to re-confirm that the relationship of these values is satisfactory.

4.57 Setting Slit S4 at 0.60 mm +/- 0.01 mm

The setting of S4 has the same precise width criterion as those of S1, S2 and S3 and it is also desirable to make S4 parallel to S3. The physical height setting of S4 does not depend upon the relationship of the Q1 S4 value to the Q1 S2 or Q1 S3 values and this factor simplifies the adjustment procedure.

The specification in Dobson 1957, Test 7 states that the Q1 S4 value should be **48.0 degrees +/- 2.0 degrees** when the Hg line 4358 AU falls centrally on S4. When Q1 S4 is not within the 2.0 degree limitation, then it means that slit S4 must be physically adjusted either upwards or downwards. When Q1 S4 is < 46.0, then adjust the physical height of S4 **upwards.** When Q1 S4 is > 50.0 then adjust the physical height of S4 **downwards**. Adjustments to S4 will be based upon the tests and measurements outlined below, but do not make any adjustments until all measurements and tests have been completed as follows:

* Perform the Hg test of Q1 S4 to determine whether or not the physical height of S4 requires adjustment.

* Measure the width of S4 at the Left, Centre and Right positions of the slit.

* Measure the distances from the bottom jaw of S3 to the top jaw of S4 at the Left and Right positions of the S4 jaw. These measurements determine whether or not the top jaw of S4 is parallel to the bottom jaw of slit S3. When the measurements agree within **0.05 mm** of each other, then the top jaw of S4 is regarded as parallel to the bottom jaw of S3

If width and/or height adjustments are needed, **select one of the jaws of S4** and make it parallel to S3 as the starting point.

After the final tightening of the S4 slit jaws, re-measure the slit width to ensure that the jaws were not disturbed during the tightening process. Perform the Hg test of Q1 S4 as a final confirmation.

4.58 Setting Slit S5 at 3.00 mm +/- 0.10 mm.

The single specification in Test 5 (Dobson 1957) requires the S5 width to be set at 3.00 mm +/- 0.1 mm. It is possible to check the parallelism of the slit with respect to the horizontal reference plane of the instrument. The S5 slit plate is mounted on the front of the photomultiplier box and held by four machine screws. The base of the multiplier box sits on the same reference flat on which the tubular S1 assembly sits. Remove the machine screws and withdraw the plate which is held in place by two guide pins. Using a caliper or a traversing microscope, measure the distance from the left side of the bottom jaw of S5 to the base of the slit plate. Repeat the measurement from the right side of the jaw. It is assumed that the base of the slit plate may be used a reference flat, therefore the left side and right side measurements should be the same. The exact distance is approximately 21 mm. (Dobson #60) but this value may be different for the older group of instruments.

When measuring the actual width of S5 it may be beneficial to remove the UV filter and the collecting lens, both of which are located in a circular housing immediately behind the slit.

At this time it is beneficial to inspect both surfaces of the UV filter. Some instruments which have been exposed to varying degrees of humid and hot conditions may develop a white oxidization deposit on the surfaces of the filter. It is not possible to remove the deposit and it is advisable to replace the filter.

4.6 Test 6. Exact Setting of Mirror M1 in Vertical Plane

The text of Test 6 (Dobson 1957) outlines the method of adjusting M1 but it does not explain that the top cover of the instrument must be in place and that the mirror adjustment is made through the right-side inspection lid. The end of the mirror mount is accessible when the inspection lid is removed.

An optional procedure may be used when **Auxiliary Q Plates and Q Pointers** are available (see para. 2.1). These devices are placed on the instrument with the top cover removed in a nearly darkened room. The auxiliary plates and pointers are very useful when several coarse mirror adjustments are needed since they may save a lot of work by not having to lift the top cover off and on the instrument many times. It is recommended that the auxiliary devices **not be used** when making the final precise setting of M1.

It is required to set M1 vertically so that Q1 reads 84.0 +/- 0.5 degrees when Hg 3129 AU passes centrally through S2 with the instrument temperature @ 15 deg. C. and when the instrument is located near sea level.

When the temperature is not at 15 degrees, the text of Test 6 (Dobson 1957) suggests reference settings of Q1 be obtained as follows:-

83.15 @ 10 deg. C.   84.0 @ 15 deg. C.   84.85 @ 20 deg. C.

However, the above values are representative of an instrument with a temperature coefficient of **0.17 deg. Q/1 deg. C.** with the instrument **located near sea level.**

If the same instrument is located at Boulder, USA (1.63 Km. ASL) then the reference settings of Q1 would be as follows:

82.45 @ 10 deg. C.   83.3 @ 15 deg. C.   84.15 @ 20 deg. C.

The general rule is that the reference Q1 values should be **reduced by 0.5 degrees** for every **100 millibar pressure decrease,** but this is an approximation only**.** It is well understood that very few instruments have the same temperature coefficient. Some of the early Dobson instruments have coefficient values as low as 0.08 deg. Q/ deg. C. while the more recent instruments containing fused quartz optics have coefficient values as large as 0.25 deg. Q/deg. C. The following table establishes reference Q1 values applicable to the temperature range from 10 to 30 deg. C. and a wide range of instrument temperature coefficients. A separate table is needed for instruments with fused quartz optics because the Q1 values change negatively with increase of instrument temperature.

Table of Reference Q1 values (Hg 3129 AU) for Instruments located near Sea Level.

	Crystal Quartz Optics					**Fused Quartz Optics**				
Temp. Coeff.	**Inst. Temp. Deg. C.**					**Inst. Temp. Deg. C.**				
Deg.Q/ deg.C	10	15	20	25	30	10	15	20	25	30
0.08	83.6	84.0	84.4	84.8	85.2	84.4	84.0	83.6	83.2	82.8
0.10	83.5	84.0	84.5	85.0	85.5	84.5	84.0	83.5	83.0	82.5
0.12	83.4	84.0	84.6	85.2	85.8	84.6	84.0	83.4	82.8	82.2
0.14	83.3	84.0	84.7	85.4	86.1	84.7	84.0	83.3	82.6	81.9
0.16	83.2	84.0	84.8	85.6	86.4	84.8	84.0	83.2	82.4	81.6
0.18	83.1	84.0	84.9	85.8	86.7	84.9	84.0	83.1	82.2	81.3
0.20	83.0	84.0	85.0	86.0	87.0	85.0	84.0	83.0	82.0	81.0
0.22	82.9	84.0	85.1	86.2	87.3	85.1	84.0	82.9	81.8	80.7
0.24	82.8	84.0	85.2	86.4	87.6	85.2	84.0	82.8	81.6	80.4
0.26	82.7	84.0	85.3	86.6	87.9	85.3	84.0	82.7	81.4	80.1

Note; Reduce the above tabled Q1 values at the rate of 0.5 degrees of Q for every 100 millibar decrease in pressure from sea level.

Adjustment Procedure.

A hypothetical situation exists where the Hg test value of **Q1 S2** = **83.3** degrees which is too low by **0.7 degrees** when compared with the Table of Q1 settings at the existing instrument temperature. Therefore, it is desired to adjust M1 so that the test value of Q1 S2 **will be raised by 0.7 degrees.** Proceed as follows:

* Make the Hg test of Q1 S2 and record the half-power point Q1 values, for example **79.5** and **87.5** which produce the mean value of **83.3 deg.**

* Remove the top cover and loosen the three bolts which hold the mirror mount to the long centre frame of the instrument. **The bolts should be loosened by no more than one half-turn.** Replace the cover.

* Loosening the bolts may have caused the vertical position of M1 to change, therefore, perform one set of half-power point Q1 values. Record the new Q1 values, for example 79.6 and 87.6. **Also record the galvanometer deflection value** which produced the half-power point value, for example **8.0 micro-amperes.**

* Set the Q1 lever at **80.3 (**79.6 + 0.7) and it will be noted that the galvanometer deflection will now **be >8.0 micro-amperes.**

* Remove the inspection lid. If the room is not darkened then place a black cloth over the lid aperture but leave access near the M1 location. Place the tip of a blade screwdriver on the edge of the mirror mount and **very gently** tap the end of the screwdriver with a hammer while watching the galvanometer needle. **The purpose is to adjust the angle of the mirror mount until the galvanometer deflection again reads 8.0 micro-amperes.**

* Repeat the Hg test and calculate the mean Q1 S2 value which should now have increased by approximately 0.7 degrees. The new test value should agree with the existing Q1Table by 0.2 degrees or less but it is not important that the new value agree exactly with the existing Table of Q1 settings because it is probable that a new Q1 Table will be created later in Test 15.

* It will be necessary to remove the top cover to tighten the three mirror mounting bolts. The process must be done very carefully by tightening each bolt in rotation by a small amount, repeating the process until all bolts are well secured.

* Repeat the Hg test of Q1 S2 to ensure that the value is satisfactory after the mounting bolts have been completely tightened.

4.7 Test 7. Check of Exact Positions of Slits S2, S3 and S4

The text of Test 7 (Dobson 1957) suggests that a series of Hg tests be done at slits S2, S3 and S4 to confirm that:-

(1) When Hg 3129 AU is central on S2 then Q1 shall read 84.0 +/- 0.5 degrees.
(2) When Hg 3342 AU is central on S3 then Q1 shall read 84.0 +/- 0.5 degrees.
(3) The results of (1) and (2) shall agree within 0.5 degrees.
(4) When Hg 4358 AU is central on S4 then Q1 shall read 48.0 +/- 2.0 degrees.

It was previously stated in para. 4.41 (Technical Discussion Number 1) that Tests 5, 6 and 7 are interdependent and should be regarded as a **composite test** whereby, when the slits have been correctly adjusted (Test 5) and mirror M1 has been correctly positioned in the vertical plane (Test 6), then the results of Test 7 outlined above should automatically be correct. The following are some example Hg tests **performed near sea level** with the Q1 values **reduced to 15 deg. C.,** showing correct and incorrect results:-

	(i)	(ii)	(iii)	(iv)	(v)
Q1 S2 (3129 AU)	84.1	84.2	84.2	84.6	84.6
Q1 S3 (3342 AU)	84.0	83.7	84.8	84.8	84.1
Q1 S4 (4358 AU)	48.3	48.1	48.7	50.2	49.5

Example (i). The results are very acceptable for each slit.

Example (ii). The individual results for S2 and S3 are acceptable but the difference between the two values is at the limit of acceptance (i.e. 0.5 deg.). The best method of improving this example would be to physically raise the height of S3 which would increase the value of Q1 S3.

Example (iii). The S2 and S4 results are acceptable but S3 is out of limits for two reasons. The overall S3 value is too large and the separation between S2 and S3 exceeds the 0.5 degree requirement. The best method to improve this example would be to physically lower the height of S3 which would lower the Q1 S3 value.

Example (iv). All values are too large but the difference between S2 and S3 is very good. The best corrective method would be to make a slight rotation of M1 (Test 6) using Q1 S2 as the adjustment reference which would effectively lower the Q1 values at all slits.

Example (v). The S2 value is too large while S3 is very acceptable and S4 is satisfactory. The easiest corrective method is to slightly rotate M1 so that the S2 value is correct and then physically raise the height of slit S3 to obtain agreement with S2. The M1 rotation will also improve the S4 value.

When deciding upon any remedial adjustments to S2, S3 and S4, try to avoid having to adjust the physical height of S2 since it creates additional work when ensuring that S2 is kept parallel to S1.

Although the text of Test 7 (Dobson 1957) does not make reference to Hg test values on the Q2 side of the instrument, it is beneficial at this time to perform the Hg tests of Q2 S2, Q2 S3 and Q2 S4 to obtain an indication of the symmetrical agreement with their respective Q1 values. The results of the Q2 tests are significant since there should be general good agreement between the values of Q1 and Q2 of any slit. This topic will be discussed in Test 11 which deals with the setting of M2 in the vertical plane.

4.8 <u>Test 8.</u> Positions of Sector Wheel, Shutters, Wedges and Q Plates

The text in Test 8 (Dobson 1957) describes the procedures for examining slits S2, S3 and S4 to ensure that the light beams pass without obstruction before reaching the slits and again pass without obstruction into the second half of the optical system. The top cover is removed from the instrument and the procedure is carried out with the help of an illuminated white card or paper and a reflecting prism or mirror. The following additional suggestions may be useful.

Checking the Optical Path on the Q1 side of the Instrument

To begin, attach the white paper with tape on the left side of the slit plate. Illuminate the white paper by placing a small lamp as close as possible to the slit plate on the left side of the instrument but do not allow the lamp to interfere with the movement of the clear/opaque shutter plate. Place the reflecting prism or mirror in the optical path near L1. It is suggested that the room be in a semi-darkened state to achieve the best viewing conditions when examining the slits.

Checking S2 and S3. Place the **long/short lever** and the **clear/opaque lever** so that the sector plates do not interfere with the illumination of the white paper at S2 and S3. The view of S2 from L1 should be totally unobstructed. Pay careful attention to the top edge of the optical wedge to ensure that it does not interfere with the optical path between S2 and L1. The R-dial should first be placed near zero, then while viewing through the reflecting prism at L1, slowly move the R-dial to the thick end of the wedge (R = 300). There should be an unobstructed view of S2 when the R-dial is moved from zero to 300. Similarly, the view of S3 from L1 should not be obstructed in any way. The bright appearance of the white paper behind S3 will slowly diminish when moving the R-dial from R = 0 to 300 due to the increasing density of the optical wedge.

Checking S4. Place the **long/short lever** and the **clear/opaque lever** so that the sector plates do not interfere with the illumination of the white paper. Slit S4 should be clearly visible when viewing from L1.

Checking the Optical Path on the Q2 side of the Instrument

Cover slits S2 and S3 with white paper on the right side of the slit plate immediately adjacent to the slits. The illumination of S4 is done by placing paper at the front surface of the achromatising lens on the right side of the wedge bridge. The illuminating lamp is placed about 10 to 15 centimetres to the right of the slits and the viewing prism or mirror is positioned near L2.

Checking S2 and S3. Set the **long/short lever** at the **'short'** position and the **clear/opaque** at the '**clear'** position. Then, **using the fingers,** rotate the **sector wheel** so that the opening for S2 is in front of the slit. Inspect S2 using the viewing prism or mirror located near L2. Next, set the R-dial to zero and rotate the sector wheel so that the opening for S3 is in front of the slit, then inspect S3 with the viewing mirror near L2.

Checking S4. Set the **long/ short lever** to the **'long'** position and the **clear/opaque lever** at the **'clear'** position. Rotate the sector wheel so that the opening for S4 is in front of the slit. Then inspect S4 from the viewing mirror near L2.

Checking the Quartz Plates Q1 and Q2.

The text of Test 8 (Dobson 1957) suggests that the quartz plates Q1 and Q2 may possibly cut off light when the plates are at their **extreme settings.** In normal operational the quartz plates are moved over an arc of about 58 degrees (from about 49 to 107 degrees) when making the AD observation. The angular positions of the Q plates at the A and D settings are not severe and do not cut off any light. However, when performing Test 15 it requires the Q1 and Q2 pointers to be positioned near 37 degrees (Hg line 3021.5 AU) and near 137 degrees (Cd line 3259.9 AU). It is possible that the effective angular settings of the Q plates may have been exceeded when set at the **extreme settings near 37 and 137 degrees.** This topic will be discussed later in Test 15.

Checking the S3 Beam at the Extreme Ends of the Optical Wedges

There are several factors which need to be inspected to ensure the correct positioning of the optical wedges. The wedges are mounted on **holding brackets** which have **V-shaped slots** on the underside. The holding brackets move backwards and forwards on **V-shaped guide tracks** which are held by machine screws to the main frame of the wedge bridge. The wedge movement is achieved by **steel tapes** which are held by **clamps** attached to the holding brackets. The steel tapes are also clamped to the circular base of a **vertical rotatable shaft.** The top of the shaft extends through the top cover and holds the **R-dial** on the outside of the instrument**.** Therefore, a rotation of the R-dial causes a movement of the optical wedges.

The rotation of the vertical shaft and the R-dial is purposely limited by a **stop-pin** located on the underside of the top section of the shaft on which the R-dial is mounted. The stop-pin comes in contact with an **adjustable yoke** near the top of the shaft whenever the dial has been rotated either fully clockwise or counter-clockwise. The total movement of the R-dial is restricted by the shape of the yoke to slightly more than 300 degrees since the R-dial is graduated from 0.0 to 300.0 degrees.

The purpose of the **stop-pin** and the **adjustable yoke** is to ensure that, when the **steel tapes** have been correctly positioned and clamped to the **wedge holding brackets,** the ends of the holding brackets will not contact the frame of the wedge bridge **before the stop-pin contacts the yoke,** either fully clockwise or counter-clockwise. The reason for this precaution is to prevent mechanical shock being transferred into the wedge holding brackets which would occur if the yoke was not properly set.

The ideal situation exists when the adjustable yoke has been set so that a full clockwise movement of the R-dial comes to rest at a reading of 0.0 degrees on the graduated scale. Many instruments do not have the ideal situation and some will reflect a stopping position >0.0 while others will be <0.0. It is best to set the yoke so that the R-dial reading will be somewhere between **0.0 and -0.5 degrees** when the **stop-pin** comes in contact with the **adjustable yoke.** The reason for the above suggested setting involves the calibration of the optical wedges (**Test 14)** where it is desirable to begin the test at exactly 0.0 degrees on the R-dial.

The yoke should not be adjusted unless the instrument is undergoing a major re-calibration process which has terminated a precise calibration period. Such a re-calibration process must include a two-lamp optical wedge calibration whenever the yoke has been adjusted.

Regardless of whether or not the yoke has been adjusted, there are other important factors to observe and verify, for example:

* When the vertical shaft has been turned to a full resting position, either clockwise or counter-clockwise, the ends of the **holding brackets** should come to rest just a few millimetres from the frame of the wedge bridge assembly. If the ends of the holding brackets touch the frame of the wedge bridge at either end, then it is necessary to loosen the appropriate **clamp** and adjust the position of the holding bracket on the **V-**

shaped guide track so that the end of the holding bracket is a few millimetres from the frame of the wedge bridge.

* After the above procedure has been done, hold the wedge bridge at eye-level while facing a lamp or window to provide illumination behind slit S3. Rotate the vertical shaft clock-wise to bring the wedge assembly to a full-stop at the thin end of the wedge (near 0.0 degrees of the R-dial), then view S3 with respect to the end of the optical wedge. Make sure that the frame which supports the ends of the wedge does not interfere with the beam passing through S3. Repeat the same process at the thick end of the optical wedge.

* Visually examine the absorbing medium at the **extreme ends** of the optical wedges since there may be small defects in the way the absorbing medium has been deposited. **It is desirable that defects not be introduced into the S3 beam when the thin end of the optical wedge is in front of slit S3.** When defects are detected which interfere with the S3 beam, it may be possible to reduce or eliminate the problem. First, determine which section of the optical wedge contains the defect. Then loosen the **clamp** which holds the **steel tape** against the wedge **holding bracket.** This allows the holding bracket to be moved by a small amount on the **V-shaped guide tracks** so that the defect is moved away from the S3 beam. If this adjustment is made, make sure that all requirements described above have been satisfied. Defects found at the thick end of the wedges may be ignored since this part of the optical wedges is infrequently used.

* The text of Test 8 (Dobson 1957) makes specific reference to the possibility of light being scattered at the edges of shutters and sector plates. Essentially, this refers to the Q2 side of the instrument (to the left of the S2, S3 and S4 slit plate) where the sector plates and the rotating sector wheel are located. In this regard, it is important that all surfaces remain blackened, especially the edges of those plates near the paths of the light beams. It is possible to repair any damaged black surfaces using a non-reflective black paint.

4.9 Test 9. Setting the Commutator Brushes

The text given in Test 9 (Dobson 1957) is fully applicable to those Dobson instruments having the original mechanical rectifier system (commutator and brushes) mounted on the shaft which drives the sector wheel (light chopper).

Operators of Dobson instruments having various types of improved electronic systems will find valuable information in Komhyr[2], paras. 5.1 to 5.4, pp 19-22.

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[2] Komhyr, W.D., Operations Handbook - Ozone Observations with a Dobson Spectrophotometer. WMO Global Ozone Research and Monitoring Project, Report No. 6, June 1980.

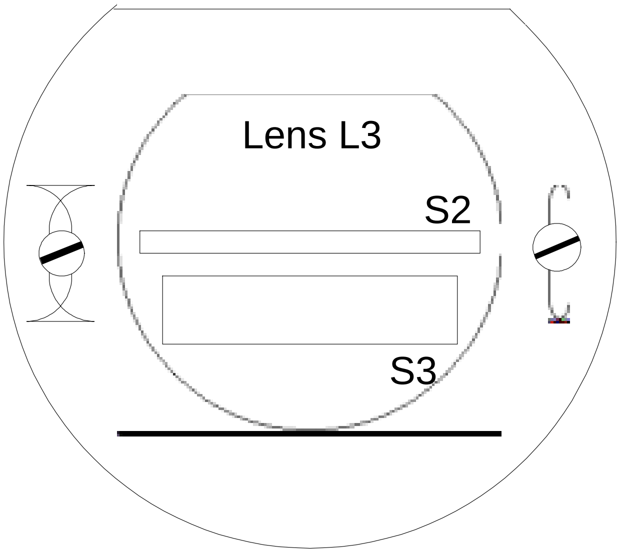

Figure 1
Position of lens L3 with respect
to slits S2 and S3

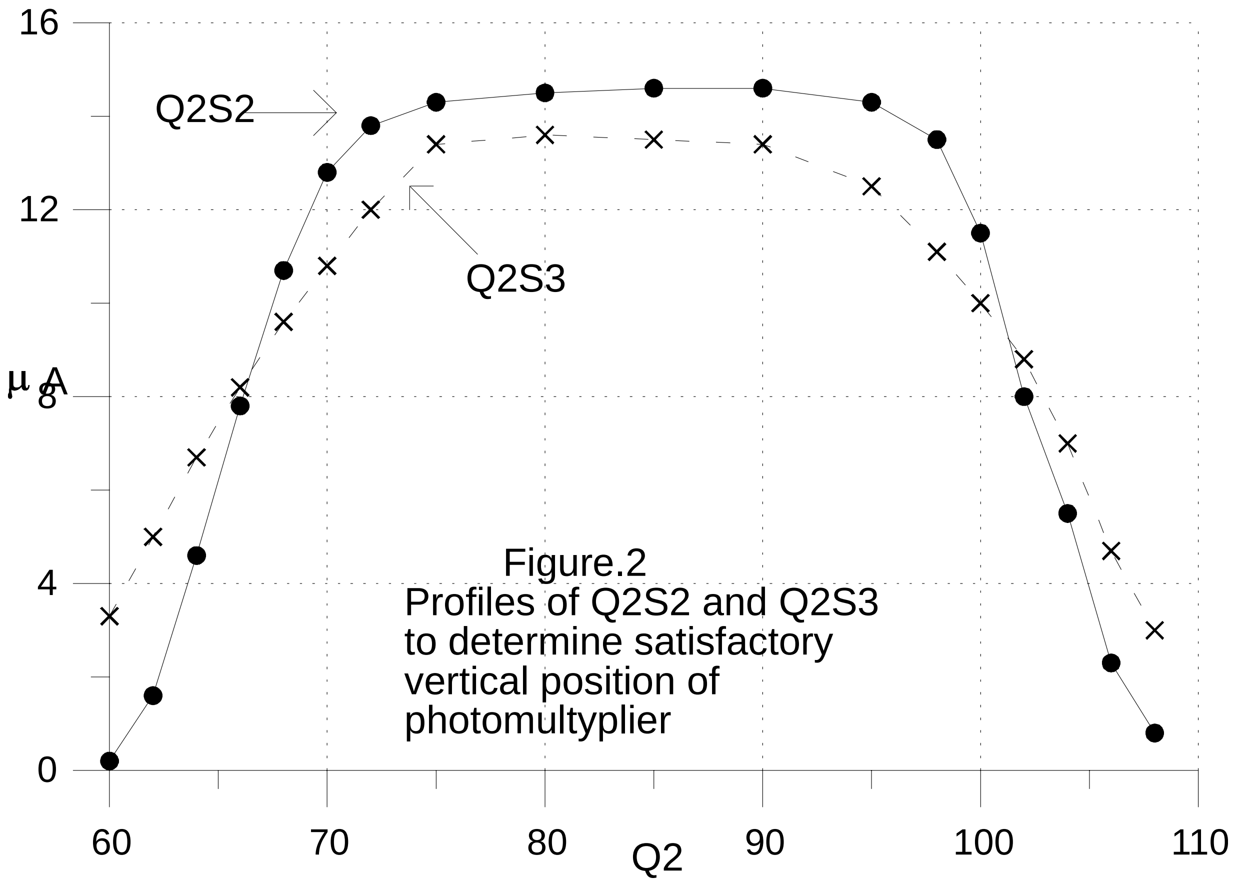

Figure.2
Profiles of Q2S2 and Q2S3
to determine satisfactory
vertical position of
photomultyplier

4.10 Test 10. Traverse Lamp

The purpose of the traverse test is to set **Lens L3** in the correct **vertical** and **horizontal** positions. L3 is the collecting lens which covers S2 and S3 on the left side of the slit plate. A special traverse device is required (see page 5, para 2.2).

It was common practice to perform the traverse test during the 1960's and early 1970's, but the procedure has not been used since about 1975. After testing many instruments it was found that there was little need to perform this test since the required position of the lens was very predictable.

When viewing L3 , S2 and S3 from the left side of the slit plate it will be seen that L3 has been vertically positioned so that S2 is very close to the height centre of the lens. Furthermore, the bottom left and right corners of S3 will be about 1 mm from the edge of the circular lens bracket. The horizontal position of L3 is judged by the ends of S2 being equi-distant from the edges of the circular lens bracket. Fig.1 illustrates a visual representation of the L3 position with respect to slits S2 and S3.

4.11 Test 11. Exact Setting of Mirror M2 in the Vertical Plane

The method of setting mirror M2 described in Test 11 (Dobson 1957) produces some uncertainty by the statement, "**Adjust mirror M2 to make Q2 equal to Q1 for the average of the three wavelengths".** Therefore, this method has been replaced by an alternate but easier method using the Hg lamp test at S2 (3129 AU).

* Make the Hg test to obtain a value of Q1 S2, (for example 84.8).

* Set the Q1 pointer at 84.8 and perform the Hg test on the **Q2 side** of the instrument to obtain a value of Q2 S2.

* The Q2 S2 value should agree with the Q1 S2 value within +/- 0.5 degrees. Differences greater than 0.5 require M2 to be adjusted in the vertical using the procedure described in Test 6 for adjusting mirror M1. A clock-wise adjustment of M2 raises the Q2 S2 and Q2 S3 values.

An extra step may be added to this method by making Hg tests of Q1 S3 and Q2 S3 since these values should also agree within 0.5 degrees. It will be found that an adjustment to M2 will alter both the Q2 S2 and Q2 S3 values. Therefore, the final adjustment to M2 should be a compromise setting so that agreement exists on both sets of values.

4.12 Test 12. To Set Multiplier to Best Position Vertically

The following text describes two test methods, (i) the original method found in Test 12 (Dobson 1957) and, (ii) an alternate method developed at NOAA Boulder after about 1980.

Test 12 suggests **two reasons** why the vertical position of the photomultiplier must be carefully selected, namely, (a) that when the position of the light falling on the photo cathode is changed by a small amount the resulting R-dial balance position will be very small, and (b) that the light should fall on the most sensitive area of the photo cathode.

The **first requirement** is the most important and is not difficult to achieve. The **second requirement** may be difficult to achieve because the most sensitive area of the photo cathode may not necessarily be the area which satisfies the first requirement. In view of the fact that most instruments have been retro-fitted with the more sensitive EMI photomultiplier tube, **the emphasis in recent years has been to satisfy the first requirement.**

The Original Method found in Test 12 (Dobson 1957)

The method described in Test 12 comprises a series of four tests, namely, (a), (b), (c) and (d), but it has been determined that a satisfactory result may be obtained by performing part (d) only.

Part (d) of Test 12 suggests a specific procedure as follows:

* Place a Standard Lamp (with the GQP) at the entrance window of the instrument and allow the lamp to warm for five minutes.

* Set the Q1 and Q2 levers for **A wavelength** according to instrument temperature.

* Make an R-dial balance then read and record the dial position for the A wavelength.

* Set the **Q2** lever **3 degrees lower** than the original position. It will be necessary to loosen the A wavelength Q2 stop. Do not disturb the Q1 lever position. Make the R-dial balance then read and record the R-dial value.

* Set the **Q2** lever **3 degrees higher** than the original position then balance the R-dial and record the R-dial value.

* Repeat the above process for **C and D wavelengths.** It will be necessary to loosen the D wavelength Q stop to achieve the 3 degree offset.

The photomultiplier vertical position is acceptable whenever the R-dial readings do not change by more than 0.20 degrees with a change of setting between Q2 = Q1 +/- 3.0 degrees.

Listed below are two examples of the final results that have been achieved when setting the photomultiplier in the best vertical position. In both instances, the multiplier required very small vertical adjustments to satisfy the criterion of Test 12 (d) with the following values:

	Q2	Ra	Q2	Rc	Q2	Rd	Remarks	Result
	47.0	31.8	74.5	34.3	105.1	35.4	Dobson 75	
Q1 fixed @-	50.0	31.8	77.5	34.3	108.1	35.4	Sept. 1978	
	53.0	31.8	80.5	34.4	111.1	35.5	AES Toronto	
Spread of R		**0.0**		**0.1**		**0.1**		Very Good
	45.2	12.9	74.3	13.1	104.6	13.4	Dobson 43	
Q1 fixed @-	48.2	12.9	77.3	13.1	107.6	13.4	Sept. 1980	
	51.2	12.8	80.0	13.1	110.6	13.5	AES Toronto	
Spread of R		**0.1**		**0.0**		**0.1**		Very Good

Listed below is an example of how the correct result for Test 12 (b) was achieved **without moving the vertical position of the photomultiplier.** The procedure occurred at the Boulder WMO Inter-comparison, July 1977 when an optical alignment problem existed with Dobson 77 (AES Canada).

The alignment problem involved the poor relationship of the Hg test values of Q2 S2 and Q2 S3 to their respective Q1 S2 and Q1 S3 values, also, the relationship of the Q2 S2 and Q2 S3 values to each other as required in Test 11 (Para. 4.11) The alignment problem was corrected by making a very small rotational adjustment to mirror **M2** and re-setting the 41 degree angular setting of prism **P2.**

	Q2	Ra	Q2	Rc	Q2	Rd	
	46.2	28.5	73.5	30.6	104.4	32.1	**Before adjustments**
Q1 fixed @-	49.2	28.5	76.5	30.6	107.4	32.1	**made to**
	52.2	28.4	79.5	30.6	110.4	31.7	**M2 and P2**
Spread of R		**0.1**		**0.0**		**0.4**	
	46.2	28.4	73.5	30.7	104.4	32.1	**After adjustments**
Q1 fixed @-	49.2	28.4	76.5	30.7	107.4	32.2	**made to**
	52.2	28.5	79.5	30.7	110.4	32.2	**M2 and P2**
Spread of R		**0.1**		**0.0**		**0.1**	

The rotational adjustment to M2 and the re-setting of P2 changed the position of the light falling on the photo cathode and this was sufficient to satisfy the criterion of Test 12 (d). It is not suggested that the above method be used, but it is described in this text because it emphasizes the fact that many optical alignment procedures of a Dobson instrument given in Tests 1 to 17 of Dobson (1957) have a definite interactive effect upon each other. This concept has been outlined in Para. 4.41 (Technical Discussion #1).

An Alternate Method of Setting the Photomultiplier to the Best Vertical Position

An alternate and easier test method has been developed as a substitute to the original method described in Test 12 (Dobson 1957). The test procedure uses the Hg lamp with the GQP at the entrance window. Proceed as follows:

*   Allow the Hg lamp to warm 10 minutes.

*   Read the instrument temperature and set the Q1 and Q2 pointers according to the value given for that temperature in the Table of Q settings.

*   Set up the instrument in the configuration for performing the normal Hg test through slit S2 using the Hg line 3129 AU.

*   Adjust the voltage to the photomultiplier so that galvanometer needle deflection is near full scale. On a full scale of twenty 20 set the needle to about 18 micro-amperes.

*   Set the **Q2 pointer to 60 degrees (do not move the Q1 pointer)** then read and record the galvanometer deflection to the nearest 0.1 ua. Set the Q2 pointer successively at 62, 64, 66, 68, 70, 72, 75, 80, 85, 90, 95, 98, 100, 102, 104, 106 and 108 degrees and record the galvanometer deflection at each position.

*   Set up the instrument in the configuration for performing the Hg test through slit S3 using the Hg line 3342 AU. The configuration for the S3 is found in Para. 3.2.

*   Read the instrument temperature and set the Q1 and Q2 pointers according to the value given for that temperature in the Table of Q settings.

*   Adjust the photomultiplier voltage to achieve a near full scale deflection.

*   Set the **Q2 pointer to 60 degrees (do not move the Q1 pointer)** then read and record the galvanometer deflection. Set the Q2 pointer successively at 62, 64, 66, 68, 70, 72, 75, 80, 85, 90, 95, 98, 100, 102, 104, 106 and 108 degrees and record the galvanometer deflection at each position.

*   Plot the galvanometer deflection values to give curves for both the Q2 S2 and Q2 S3 sets as shown in Fig 2.

The ideal vertical photomultiplier position exists when the Q2 S2 curve (slit 2) shows a level plateau between Q2 = 75 and 95 degrees. **An acceptable result exists when the Q2 S2 values between 75 and 95 degrees agree within about 0.3 micro-amperes when using a galvanometer with a 20 ua full scale. Otherwise, adjust the vertical position of the photomultiplier.**

A further judgement may be made based upon the curve of the Q2 S3 values (slit 3), but it will be usually found that the plateau of the S3 curve will have a different slope than that of the S2 curve. **It is difficult to make the slopes of the two curves agree but the final vertical positioning of the photomultiplier must be based upon the flatness of the S2 plateau between 75 and 95 degrees.** In some instances, the final vertical positioning of the multiplier may show the S3 plateau slopes oppositely to that of the S2 slope. It is not always necessary to plot the curves as in Fig. 2 since the recorded test values clearly indicate the needed requirements.

Adjusting the Photomultiplier in the Vertical.

The photomultiplier mounting socket is attached to a rectangular metal plate on the rear side of the multiplier box. The plate is held by four machine bolts which need to be loosened. It is difficult to gain access to the plate because of a string of electrical resistors mounted on insulating material in front of the rectangular metal plate. Do not over loosen the machine bolts, (one full turn is sufficient).

Depending upon the results of the above tests, when the Q2 S2 values at 75 degrees are larger than the values at 95 degrees, then the height of the photomultiplier must be lowered.

A method of maintaining a reference height is to use feeler gauges and measure the distance between the bottom of the back metal plate and the base on which the multiplier box sits. It is advisable to use the auxiliary Q Plates and Q Pointers when available since the work may be done in a near darkened room without having to frequently remove the top cover of the instrument. During the adjustment process it is sufficient to do the Hg test at 75, 85 and 95 degrees in order to assess the levelness of the plateau.

After the final adjustment has been made and the four bolts have been tightened, re-check the test values to verify that the tightening process has not changed the photomultiplier position.

4.13 Test 13 To Set the Optical Axis of the Sun Director and mark Position of the Lens to give Focused Image

The text of Test 13 (Dobson 1957) is fully applicable to all Dobson instruments. The procedure comprises two parts, namely Tests 13.1 and 13.2. All instruments must have the optical axis of the sun director set according to Test 13.1.

Those instruments located at latitudes equal to or less than about 50 degrees (North or South) need only be concerned with Test 13.1 since the airmass value (MU) at the winter solstice will allow the **Direct Sun Ground Quartz Plate** (DSGQP) observation method to be utilized on either December 21 (Northern Hemisphere) or June 21 (Southern Hemisphere) Those instruments located at latitudes greater than about 50 degrees where it is necessary to use the **Focused Image** method of sun observations must perform Test 13.2.

4.14 Test 14 Calibration of the Optical Wedges

The text of Test 14 (Dobson 1957) comprises three parts, namely Tests 14.1, 14.2 and 14.3. It has not been necessary to perform Test 14.2 since about the mid 1960's. However, it is worthwhile to read the entire text to understand the required interaction between 14.1 and 14.2.

Test 14.1 describes a calibration method using a "two-lamp" system which, in 1957, was able to examine the density gradient of the optical wedge on a two to one basis to provide a **true ratio** (log 2 = 0.301) at the **thin end of the optical wedge**. The lack of light intensity provided by the early equipment, combined with the overall lack of instrument sensitivity, proved insufficient to examine the density gradient of the middle and thick ends of the wedge beyond about R = 130 degrees. With the advent of quartz halogen lamps in the late 1960's it has been possible to construct "two-lamp" calibration equipment providing sufficient intensity to examine the density gradient along the full length of the optical wedge. Thus, it has become unnecessary to perform Test 14.2.

Two-Lamp Calibration Equipment.

The quality of present day calibration equipment has greatly enhanced the overall task of establishing the density gradient of the optical wedge. The major improvement has been due to the availability of 250 watt quartz halogen lamps controlled by very stable power supplies. In addition, the use of stepping motors to control the shutter mechanisms, cooling fans to reduce heat transfer to the instrument and optical encoders to detect and record the R-dial test values has eliminated much of the tedious manual work. It is now possible to establish density gradient curves of the A, C and D wavelengths in a few hours as opposed to two or three days with earlier equipment. The development of the present day wedge calibration equipment is attributable to the **NOAA, Boulder, Ozone Laboratory** where it is maintained. An additional set of equipment based upon the NOAA, Boulder design is nearing completion at the **Deutscher Wetterdienst Meteorologisches Observatorium, Hohenpeissenberg, Germany** for use in Europe. Similar but less sophisticated lamp equipment requiring manual operation and data recording was developed at **AES, Toronto** in the 1970's using 250 watt lamps, solenoid operated shutters and a water cooled lamp unit which was effective in limiting instrument temperature increases to about 5 C. degrees over a period of eight hours.

The full text of Test 14.3 (Dobson 1957) dealing with the construction of density gradient tables is no longer applicable since it requires the results of Test 14.2 which is not required when the true density ratio (log 2) of the full wedge may be determined using the present day calibration equipment. Consequently, calibration tables of true density ratio are readily prepared by computer software using the recorded R-dial test values. The resulting calibration tables are commonly referred to as **G-Tables (or R - G Tables).**

The individual G-Tables for wavelengths A, C and D represent the density gradient based upon log 2. It is then necessary to add a constant (**K**) to each G table to produce values of **N (R - N Tables)** whereby if the instrument could be taken outside of the earth's atmosphere then an observation of the sun using the S2/S3 pair of wave-lengths would indicate the **R-value** pertaining to **N = 0 (zero).** The value **K,** commonly referred to as the **extra-terrestrial constant,** must be individually determined for the A, C and D wave-length pairs and is usually determined by comparing the instrument under calibration with a reference standard instrument using the **Direct Sun Ground Quartz Plate** observation method.

Test 4.15 Test 15 Determination of Values of Q for Wave-lengths A, B, C and D

Test 15 (Dobson 1957) describes two methods of determining the Q setting values for wave-lengths A, B, C and D. Both methods, 15.1 and 15.2, have been extensively used in the past. However, commencing with the 1977 WMO World Inter-comparison at Boulder, the decision was made to adopt one procedure in order to achieve the maximum degree of standardization amongst all instruments. Consequently, Test 15.2 became the adopted procedure using spectral discharge lamps.

The principal reason for adopting Test 15.2 stems from the fact that Q15 degree fixation values produced by 15.1 and 15.2 do not always agree. Generally, the resulting fixation Q values agree for wave-lengths A, B and C but the results for wave-length D often differ by as much as 0.3 degrees of Q.

The procedures for **Test 15.2** are precisely described and explained (Dobson 1957) and need no further definition. At this time however, it is worthwhile to outline some idiosyncracies which have been experienced in the past.

(i) The **'Q1 and Q2 Stops'** for wave-lengths A and D must be removed from the front of the instrument in order to make those tests where the **Q-levers** need to be set at the top and bottom ends of the Q-scales. The stops are held by slotted bolts which normally have locking nuts on the inside of the instrument. The nuts may be accessed through the inspection lids.

(ii) It is important that the instrument temperature be reasonably stable during the test of any discharge lamp. In this regard, it is advisable to warm the lamps before the lamp holder is placed on the instrument to minimize heat transfer from the lamp to the instrument. Most discharge lamps reach stable output after about five minutes of warming.

(iii) The normal monthly Hg Lamp Test is usually achieved by recording a **set of five half-power point values** each of which provides a **mean Q1 value.** When the lamp has been sufficiently warmed the mean Q1 values will be very repeatable and provide an accurate **overall Mean Q1.** The same procedure is followed for each discharge lamp. Some lamps, particularly the Helium and Thallium, tend to produce more variable results and it is in order to record more than five sets of test values if this type of variability is experienced.

(iv) The **Thallium** line (3229.8 AU) sometimes produces results which, when plotted on a curve of **Q15-Qs,** will **fall well below** the line of the suggested smoothed curve. (See Fig. 3 **Curve B** of this text). Caution is advised when drawing a smoothed curve using a point from the Thallium test which appears to be doubtful.

(v) The shape of the smoothed curve of Q15-Qs found in Fig. 22 (Dobson 1957) is typical of many instruments where a peak is found near 3100 AU. The peaked shape does not always exist and some instruments will produce a curve wherein the Q15-Qs values will be reasonably constant from about 3100 to 3260 AU creating a plateau in that region. This feature has been seen mostly in the older group of instruments.

(vi) The **Indium** line at 3256.1 AU and the **Cadmium** line at 3259.9 AU are separated by <4 Angstroms and one would expect that their respective test results should produce nearly identical values of Q15-Qs. However, it is often found that the two test points differ by as much as 0.2 degrees with the Cadmium result always producing the more positive value. It is then questionable as to which point should be favoured when drawing the smooth curve of Q15-Qs. The reason for the difference is not known but one explanation may be found in Test 8 (Dobson 1957) which states, "**See that the quartz plates Q1 and Q2 do not cut off any light at their extreme settings".** In this regard, the Q plates on some instruments may be near to their limits of usefulness when performing discharge lamp tests at wave-length values > 3250 AU., especially when using the Cadmium line at 3259.9 AU. One would then want to favour the test point from the Indium line when drawing the smoothed curve.

(vii) The ideal situation would be to have the instrument temperature at 15 degrees when the tests are performed since the process of producing the Q15-Qs curve requires the test results to be reduced to the 15 degree equivalent using the temperature coefficient of the Hg line 3129.6 AU and the Temperature Factors (**f**) found in Table 1 of Test 15.2 (Dobson 1957). It is recommended that the tests be performed as close as possible to 15 degrees C and, if possible, repeat the tests at a significantly different instrument temperature. The results of both sets of tests should be very similar when reduced to the 15 degree equivalent. If not, then it suggests that the temperature coefficient of the Hg line 3129.6 AU needs to be verified.

Discharge Lamp Tests at Different Altitudes above Sea-level.

The shape of the Q15-Qs curve depicted in Fig. 22 Test 15.2 (Dobson 1957) is typical of what one expects when the discharge lamp tests are performed near sea-level. However, the effective refractive index of quartz in air varies with air pressure and causes the shape of the curve to change significantly when the lamp tests are performed at various altitudes above sea-level. This feature is illustrated in Fig. 3 of this text which shows three curves pertaining to D 77 obtained at Toronto (0.2 Km), Boulder (1.63 Km) and Mauna Loa (3.4 Km).

Test 15.1, Often referred to as the 'S-Curves' or 'Zenith Blue Sky Curves'.

It has been previously stated that Test 15.1 should not be used to establish the Q1 fixing values. However, it is beneficial to know the procedure in the event that the existing fixation Q values need to verified when the necessary discharge lamps are not available. The procedure is precisely described in Test 15.1 (Dobson 1957) but certain peculiarities and suggestions are documented below.

(a) The S-curves are normally well defined at wave-lengths A, B and D but not always at wavelength C.

(b) On any given day the best S-curve definition is obtained near solar noon when the Mu-value is <2.5.

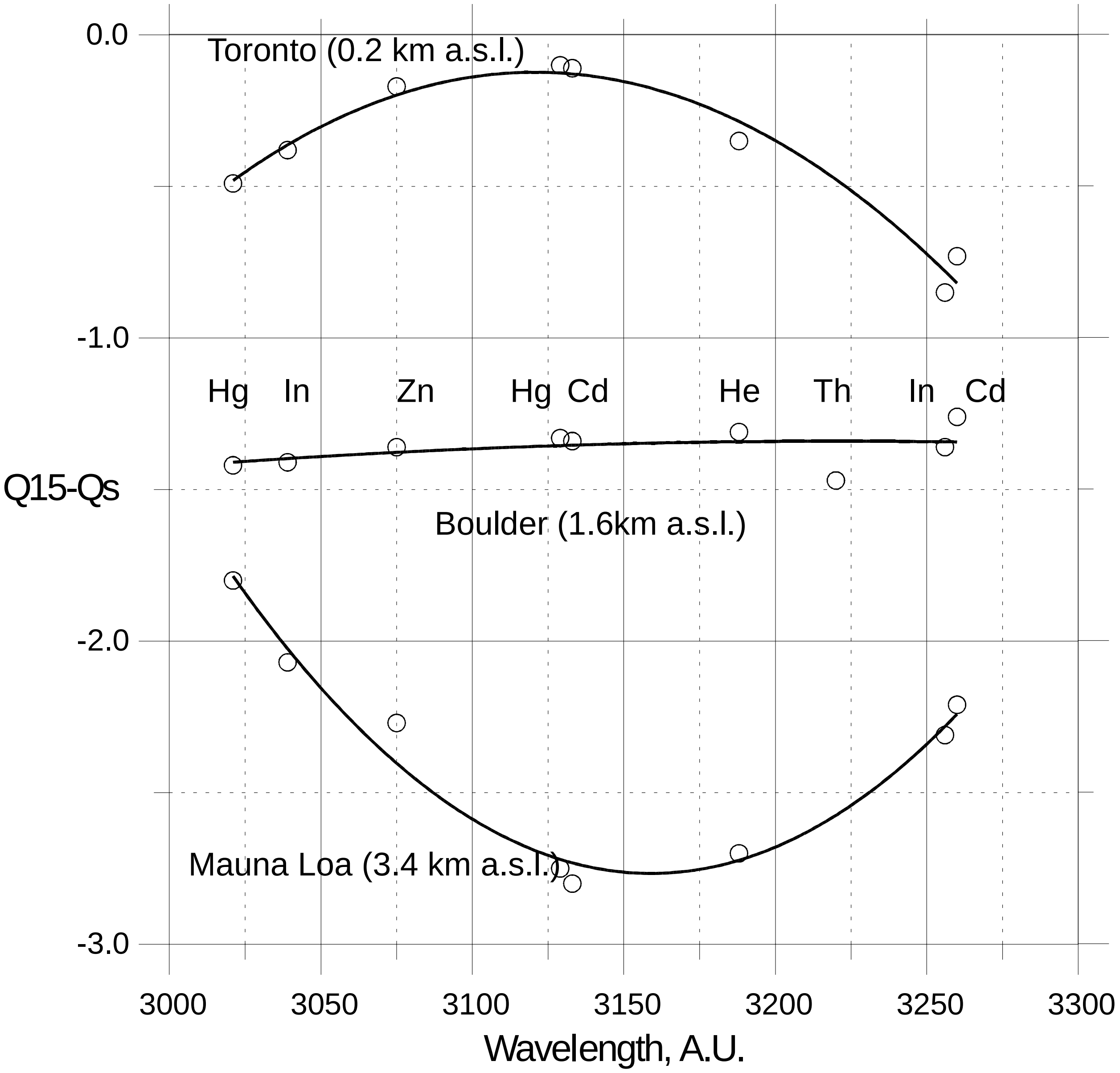

Figure 3.

Spectral discharge lamp tests at various altitudes above sea level using Dobson 77.

(c) The curve definition is greatly reduced when the total ozone value is large. For example, when ozone is >400 DU the S-shape will usually not exist at wave-length C and will be weakly defined at wave-length B. When ozone is >500 DU the wave-length C values will produce a straight line and other wave-lengths will produce poor definition.

(d) The S-Curve method has been alternatively performed using the Direct Sun Ground Quartz Plate (DSGQP) method of observing and produces results compatible with the Blue Sky technique.

Test 4.16 Test 16 Variation of Q1 with Temperature

Test 16 is essentially an extension of Test 15 wherein the **Q15 deg. C fixing values** have been established for the **Hg Line** 3129.6 AU and the standard wave-lengths **A, C and D. (**wave-length B is not used). An important requirement of establishing the fixing values is in knowing the **temperature coefficient** of the Hg line.

The text of Test 16 (Dobson 1957) suggests the need to accurately determine the temperature coefficient of Q1 for the Hg Line 3129.6 AU. In most instances, the coefficient value has been determined for instruments which have been in operational use for several years. However, it is beneficial to re-confirm the existing coefficient value for an instrument which has undergone optical adjustments. This can be done by performing the normal Hg lamp test (through slit S2) when the instrument temperature is very steady. Hg tests should be made over a wide temperature range of about 15 to 20 Celsius degrees and preferably at 2 to 3 degree intervals in this range.

Experience has shown that the temperature coefficient remains very constant over many years, although there is a possibility that a slow deformation in the metal casting of the instrument may cause the coefficient value to change. Therefore, it is advisable to re-confirm the value every few years and this may be achieved by graphically plotting the monthly Hg test results of **Q1 Test versus Instrument Temperature.**

The text of Test 16 (Dobson 1957) suggests that the **variation of Q1 versus temperature** may be **graphically** represented as shown in Fig. 24. A more convenient method is to create a table, commonly known as the **Table of Q1 Settings,** using the temperature coefficient of the Hg Line 3129.6 AU and the Q1 fixing values for wave-lengths A, C and D determined in Test 15.

Test 4.17 Test 17 Dial Readings for the "Standard" Lamps and "Universal" Lamps

The text of Test 17 (Dobson 1957) suggests that the calibration status of each instrument may be monitored by **Standard Lamps** and/or **Universal Lamps.** This procedure has been previously described in Chapter 3, pages 6 to 8.

Appendix A

An Alternate Method of Setting Lenses L1 and L2 to Correct Focus Position

Introduction

Reference is made to **Dobson, G.M.B., Adjustment and Calibration of ozone spectrophotometers in Annals of the International Geophysical Year, V, Part 1, 90-113, Pergamon Press, 1957.** Test #3 describes the method of setting Lens L1 to the correct focus position. The method is lengthy and tedious requiring the use of photographic plates and the need to set slit S1 to a very narrow position, thus creating the difficulty of re-setting S1 to its original precise width after L1 has been has been correctly focused. An alternate method developed at AES Canada (circa 1978) is described here and, by comparison, is equally precise and less tedious to perform since the procedure does not require to narrow the width of S1.

The Test Device

The method requires construction of a device which positions the filament of the Hg lamp at a distance above S1 equivalent to the distance from S1 to L1 (about 15 inches or about 37.5 cm).The whole device is essentially a traversing system which allows the Hg lamp to be moved at precise intervals along the length of the Dobson, in the area immediately above the entrance window and S1. The device comprises two major parts.

Part 1. The first part consists of a circular pedestal plate with a three-point foot system using threaded bolts to allow levelling. The plate fits around the Dobson inlet window similar to the base plate of the Standard lamp housing. A vertical shaft about 9 inches long is rigidly attached to the back of the base plate behind the entrance window. A frame is rigidly attached to the top of the vertical shaft. The essential part of the frame is a stainless steel rod on which the traversing device (Part 2) is able to slide. A suitable scale, in inches or centimetres, is mounted on the front of the frame. The scale is mounted so that one of the major intervals on the scale is exactly perpendicular to the centre of the Dobson inlet window.

It is necessary to hold Part 1 in a fixed position, without movement, and this is achieved by placing heavy duty elastic bands to the three feet on the base plate and anchoring the bands to the lower parts of the Dobson frame. The base plate levelling is achieved by adjusting the threaded bolts. **A word of caution!** Make sure that the base plate does not rest on any of the feet on which the sun director sits.

Part 2. The second part consists of a plate on which the Hg lamp is mounted. A metal block on the underside of the plate contains a machined hole into which the stainless steel rod of Part 1 is fitted. A tubular bracket is mounted over an aperture at the centre of the plate and the Hg lamp housing fits into the bracket. The aperture is elongated, approximately 3/4 x 1/2 inch, with the long dimension positioned across the instrument to correspond with the length of S1. The narrow 1/2" aperture is designed to prevent over flooding the Dobson entrance window with a beam which is too wide. A scribe mark is placed on the front of the plate and its position corresponds with the centre of the narrow 1/2" aperture. The scribe mark is easily referenced to the scale mounted on Part 1 thus allowing accurate positioning of the Hg lamp filament with respect to the centre of the Dobson inlet window.

Test Methodology

The overall procedure is to **remove the GQP** from the entrance window and make a series of Hg tests at precise traverse positions across S1. The original AES Canada device has a scale in inches and it is normal to make tests starting at **1/2** inch to the left of vertical and proceeding at **1/8** inch intervals to **5/8** inch to the right of vertical. This gives a total of ten tests. Read and record Q1 for each traverse position. There are three important procedures and points to consider;

(1) Place a scribe mark on the sleeve of the L1 tube at the position on the tube adjacent to the collar which holds the tube, (see Fig. 1). This can be done by removing the right-side inspection lid. Make the first series of tests with lens L1 at its original undisturbed position as defined by the scribe mark on the collar. Using a caliper, measure the distance 'd' from the end of the lens sleeve to the edge of the collar which holds the sleeve. Record the 'd' value.

(2) It may be possible to obtain additional tests to the left of the 1/2" start point and to the right of the 5/8" end point of the traverse but this is very much determined by the instruments field of view and the constricted aperture. These extra tests should be made whenever there is sufficient instrument response to give a satisfactory micro-ammeter deflection.

(3) The normal Hg test usually consists of five sets of the half-power point 'Q' values. For the focus test, it is sufficient to do one or two sets of half-power points at each of the traverse positions provided that the lamp is well warmed and giving stable output.

Focus Test Interpretation to Determine the Correct Setting of L1.

The following documentation originates from work performed at AES Canada on behalf of WMO. The instrument is not identified.

Figure 1 shows a series of plots of the **Mean Q1 values** versus **Hg lamp traverse position** for various positions of lens L1. The best smooth curve is drawn for each set of plots. The original undisturbed L1 position is depicted in **curve A** which shows a clearly defined 'S' shape**.** The distance value **'d'** is **10.00 mm.** The **Delta Q** value**,** as defined by the 'S' curve is **3.5** degrees (86.6 - 83.1).

Curves B, C, D, E and F depict the test results at several values of **'d'.** The 'S' curves become less pronounced and the **Delta Q** values decrease when lens L1 is moved

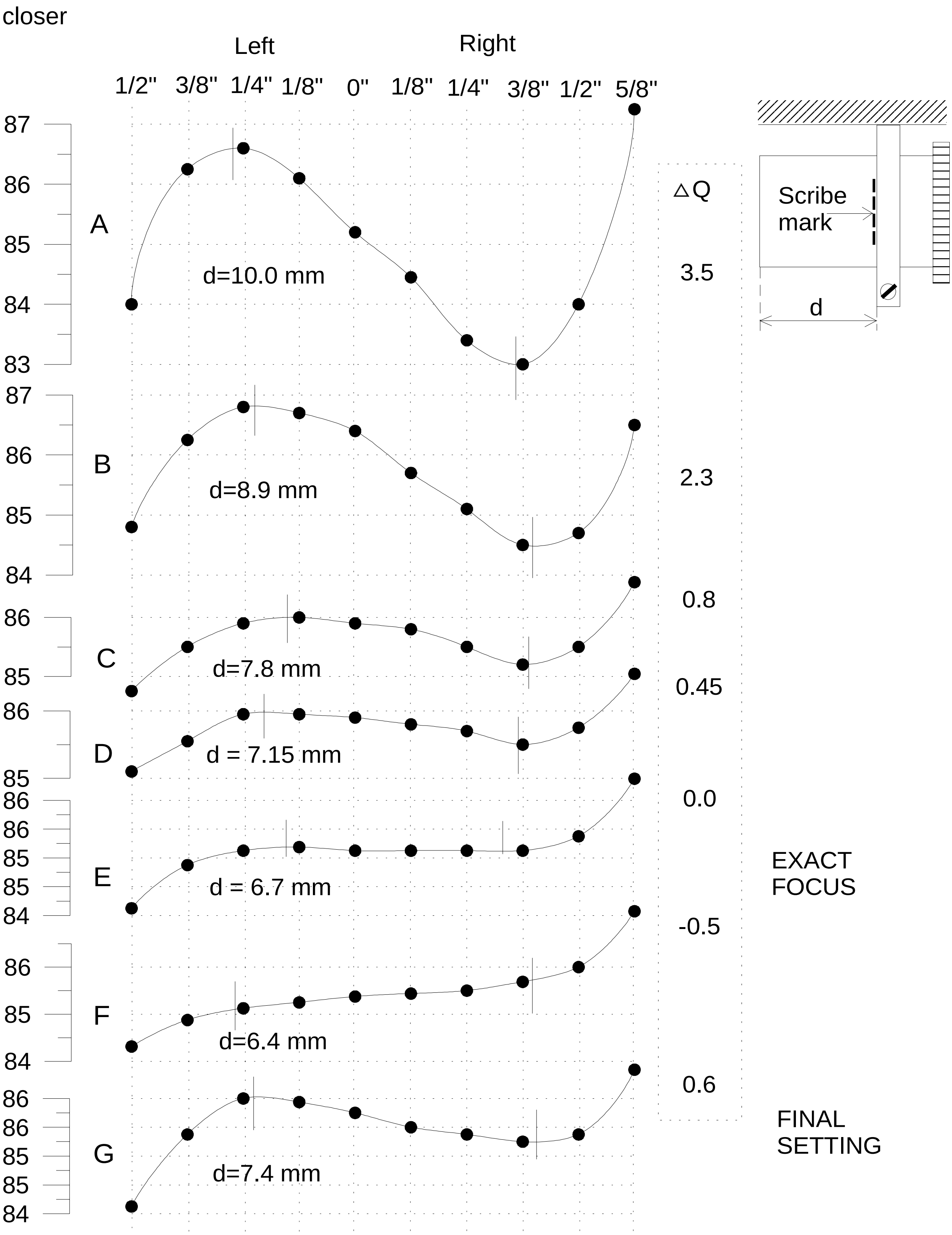

Figure 1. Traverse Curves of Q1S2 at different lens positions 'd'.

to prism P1. A position is reached (**curve F**) where the 'S' shape is not clearly evident and the sign of **Delta Q** inverts. If further tests had been made, the 'S' shape would disappear and the plot would create a sloping straight line.

In this example, the **'exact'** focus position of L1 is found at **'d' = 6.7 mm, curve E,** which shows a flat plateau and **Delta Q = 0.0**. This is the position of lens L1 which would produce the sharpest image of lines 312.6 and 313.1 nm if the photographic plate method was used (AC Test 3).

The '**final setting'** is achieved by moving the lens holder **0.7 mm further away from prism P1** than the position found for **'exact'** focus**.** In this case, make **'d' = 7.4 mm.** It is suggested to make a final traverse test after the lens sleeve has been clamped by the collar. This is depicted by **curve G.** The final setting generally produces a **Delta Q** value in the order of **0.5 to 0.6** but it is difficult to maintain a constant value from instrument to instrument because the final collar clamping may cause distortion and move the lens sleeve to a slightly different horizontal position**.**

Fig. 1, curve A, is an example of a very badly positioned lens L1. The final setting required moving the lens sleeve by 2.6 mm from the original position (10.0 -7.4 mm). The example was chosen because it clearly demonstrates the effect of moving the lens by that amount. It will generally be found that most instruments will not require such a large adjustment.

The above procedure determines the setting of lens L1 by moving the lens 0.7 mm further from P1 than where exact focus was found for 312.6 and 313.1nm at S2. The reason for this is not explained in AC Test 3 but it is assumed that the 0.7 mm shift becomes a compensation for slit S3 since the focal plane in the area of S2 and S3 is a curved surface.

According to AC Test 3, **lens L2** is set by physical measurement **at the same distance from S2 as L1.** This is not an easy procedure to perform because the location of slit S2 underneath the photomultiplier box makes it difficult to make a physical measurement between S2 and L1. One method is to remove the photomultiplier box which then exposes the top of the S2/S3 slit plate. It then becomes easier to make a physical measurement from S2 to L1 and from S2 to L2 using a caliper device with a large extension capability. If a large caliper is not available, the measurement may be made in two stages, first from S2 to the left edge of the sleeve which holds L1 and second, from the end of the sleeve to the centre of L1. To remove the photomultiplier box, first remove the top lid of the box. There are three or four screws in the base of the box which anchor the box to the main frame of the Dobson. After removal of these screws, the box may be moved to the rear without having to make any electrical disconnections. A locating pin on the surface of the main frame ensures that the box will be restored to its original position when the anchoring screws are restored.

The original AES traverse device contains an optional feature in the form of a slotted bracket which is fitted where the Hg lamp holder is located. The bracket is designed to accept the conventional WMO type Standard lamp fixture for the purpose of performing A/C Test 10 (the setting of Lens L3 in the correct vertical and horizontal positions).

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There are no mechanical drawings available for this device. Anyone interested in fabricating the AES device may contact the author at:- **9 Lehar Cres., North York, Ontario, Canada. M2H 1J4.** Telephone +416 494 2622; Fax +416 494 9190 or by e-mail at <archie@inforamp.net>

Appendix B

Trends and Variations in Standard Lamp Test (SLT) Results

Introduction

It is understood that a Dobson spectrophotometer should exhibit fairly constant standard lamp test results provided that the instrument is well maintained and the test procedures are correctly followed. However, many years of experience with several instruments has shown that test results may vary. The causes of some variations are understood and the reasons for other changes are sometimes difficult to identify. This text offers suggestions for avoiding some of the changes and explains the reasons why particular changes may be taking place. In some instances the changes cannot be immediately halted without replacing certain optical components.

One important aspect of maintaining a Dobson spectrophotometer involves the environment in which the instrument is used and where it is stored when not in use. Controlling the humidity inside the instrument is most important and every effort must be made to keep an adequate supply of a drying agent such as silica gel inside the instrument. Failure to do so will allow moisture to be deposited on the optical surfaces resulting in trends and variations of standard lamp test values. Instruments located in equatorial and tropical regions where there are wet seasons will need special care. For example, equatorial locations near sea level almost invariably experience high levels of humidity throughout the year, while other locations may have wet and dry seasons. Spectrophotometers at middle and high latitude locations are also subjected to detrimental conditions creating subtle instrument changes which are not easy to identify. All instruments require certain basic maintenance which will minimize the effects due to local environmental conditions.

The different SLT trends witnessed over a period of forty years have exhibited certain characteristics which fall into the following categories :

Category (1) **Increasing** test R-values which are generally **uniform versus wavelength.**

Category (2) **Increasing** and **decreasing** test R-values which are generally **uniform versus wavelength.**

Category (3) **Increasing** or **decreasing** test R-values which are **non-uniform versus wavelength.**

Trends in SLT results due to a dirty Ground Quartz Plate (GQP)

This is an example of Category (1) whereby the SLT R-values **generally increase uniformly versus wavelength**. A spectrophotometer calibrated against a reference standard is given new R-N Tables based on a Direct Sun GQP inter-comparison. The extra-terrestrial constants of the standard instrument are transferred to the new R-N tables of the instrument under test. The GQP of the instrument under test **must be clean** when this procedure is done. Standard Lamp tests performed on the test instrument at the end of the intercomparison produce the **Reference R-values** against which all future lamp tests are compared. Failure to keep the GQP clean results in test R-values which do not agree with the Ref. R-values. A dirty GQP changes the extra-terrestrial constants of the instrument and observations made with a dirty GQP should be corrected by Standard Lamp Corrections (SLC's) represented by **Ref. R - Test R.**

The top surface of the GQP may become contaminated from touching with the fingertips and should be washed on a regular basis, preferably **before** performing the monthly lamp tests. An easy cleaning method is to wipe the plate surfaces using a tissue moistened with soap and water, **then rinse both surfaces of the plate very thoroughly with water and dry with a clean tissue.** The result of washing a dirty GQP is shown by an example in Table 1 where the plate had not been cleaned for four years.

Table 1

Dobson No. 90. Bangkok. Standard Lamp No. 90Q1

Date	R a	R c	R d	
01 10 87	38.7	39.9	40.4	<--- Reference Values
12 12 87	38.4	39.6	39.7	
30 03 88	38.6	39.7	40.1	
01 07 88	38.7	39.8	40.1	
31 10 88	39.2	40.1	40.6	
03 02 89	39.1	40.3	40.5	
01 06 89	39.6	40.6	40.9	
30 09 89	39.9	41.0	41.3	
31 01 90	40.0	41.0	41.4	
31 03 90	40.4	41.4	41.7	
31 07 90	40.5	41.7	41.9	
01 10 90	40.6	41.7	41.7	
01 02 91	40.7	41.7	42.0	
02 05 91	40.7	41.7	42.1	
31 08 91	40.8	42.1	42.5	
01 10 91	41.0	42.0	42.5	
14 11 91	41.2	42.3	42.6	<--- **Before plate washed**
14 11 91	38.2	39.3	39.6	<--- **After plate washed**
Delta R (Before - After)	**3.0**	**3.0**	**3.0**	

The test R-values after washing the plate do not correspond exactly with the Reference R values from four years previous but this may be attributable to other changes within the instrument. The significant result is that the values of Ra, Rc and Rd lowered uniformly by 3.0 R-units after washing the GQP. A more accurate representation of instrument performance over the four-year period could have been achieved by regularly washing the plate. **Regular cleaning of the GQP is very important.**

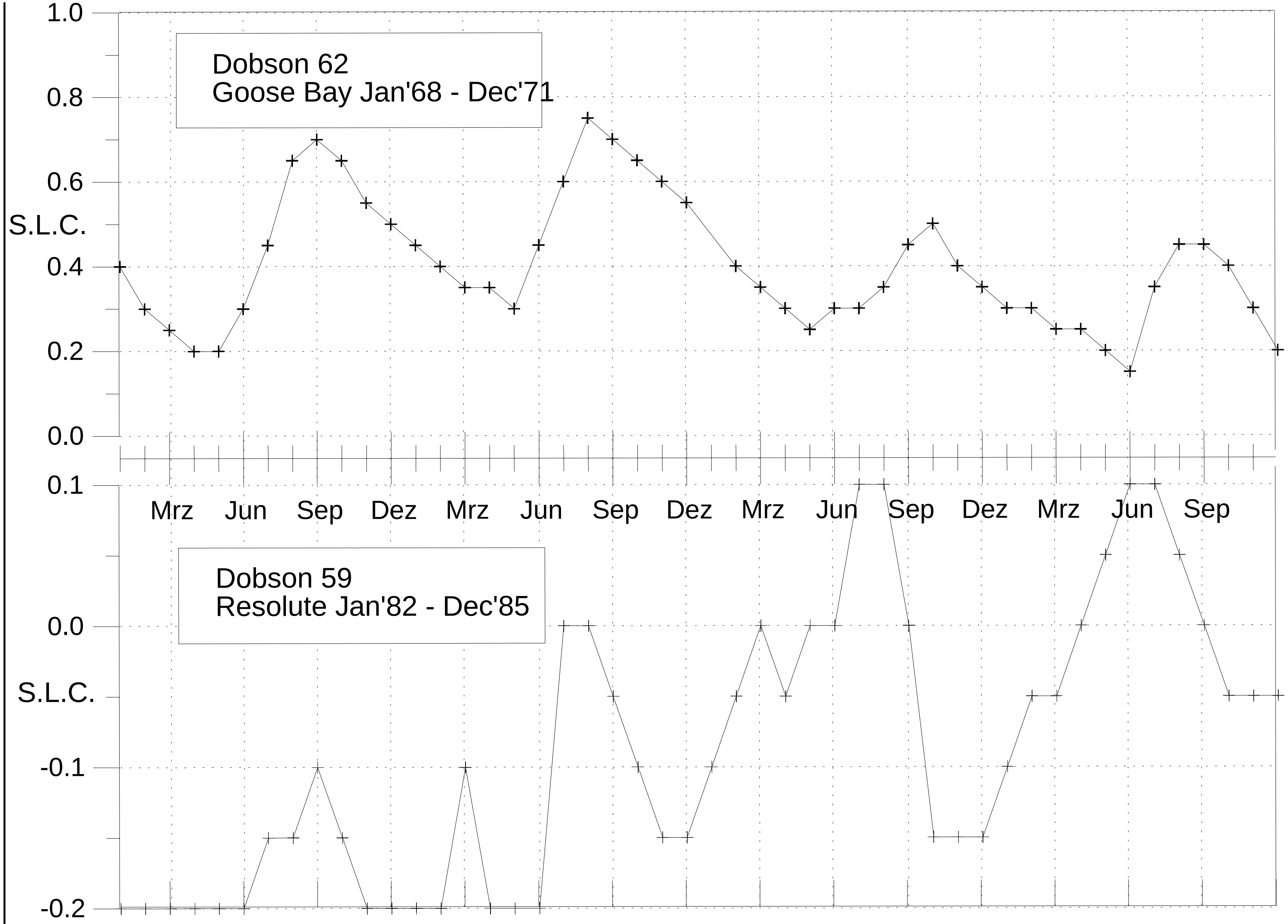

Figure 1. Seasonal variations of Standard Lamp Corrections

Seasonal Variations in Standard Lamp Test results

This is an example of Category (2) whereby the SLT R-values may **increase and decrease uniformly versus wavelength.** Clear evidence exists that **seasonal variations** of lamp test results take place and are repeatable from year to year as shown in Figure 1 which shows standard lamp corrections (SLC's) of Dobson 62 over four years at Goose Bay, Canada. Each plot is the mean SLC of wavelengths A, C and D but it is noted that the individual wavelength values exhibit the same trends. Lamp tests were carried out twice monthly and the plotted values represent three-month running means.

The climate of Goose Bay (N 53, W 60 deg) is semi-continental with less severe temperature extremes than those of a true continental situation. The general climate is greatly influenced by the close proximity to the Atlantic ocean with extensive periods of cloud, precipitation and moderately high humidity.

Dobson 62 was housed in a small but well insulated shelter heated by thermostatically controlled electrical units. The atmosphere in the shelter was quite dry during the late autumn, winter and early spring months when the heaters were in continuous use, but during the remainder of the year the atmosphere in the shelter was comparable to the general outdoor conditions. It is important to note that the instrument was used indoors at all times by making observations through hatches which were tightly sealed after each observation during the winter months but remained open for a few hours each day during the late spring and summer months.

The plot of Figure 1 suggests that Dobson 62 was undergoing a drying-out process from about September to May, coinciding with the dry electrical heating of the shelter. During the remaining months the instrument was absorbing moisture when the temperature and humidity conditions in the shelter were influenced by the outdoor conditions.

Figure 1 also shows a four-year plot of SLC's obtained with Dobson 59 situated at Resolute, Canada (N 74, W 95 deg) using the same criterion for establishing the values.
The instrument was housed in a well insulated building heated by forced air from an oil burning furnace which produced a very low humidity level. The climate of Resolute is such that heating is required throughout the year thus creating a very dry environment. for many months. The seasonal SLC variations at Resolute are less pronounced and the yearly cycles (peaks and lulls) do not correspond with those at Goose Bay.

Trends in SLT R-values due to changes in the Optical Wedge Density Gradient.

This is an example of Category (3) whereby the test R-values **decrease non-uniformly versus wavelength.** Most of the SLT trends witnessed over a period of forty years have demonstrated **increasing** R-values. However, two particular instruments (D 59 and D60) experienced a period in their history when the test R-values decreased very steadily and non-uniformly with wavelength. In dealing with this topic, the Standard Lamp Test history of **Dobson 60** has been used extensively since the data were readily available and the author was directly involved in the calibration and maintenance of the instrument. It is noteworthy that the history of Dobson 60 relevant to this text begins in the early 1960's at Toronto and continues with the transfer of the instrument to Churchill in December 1964 and ends in August 1989. There were **two significant events** contributing to the presented arguments.

Event 1, May 1972. The optical wedge was converted to the 'air-space' configuration.

Event 2. May 1978 to September 1979. Dobson 60 at AES Toronto. A new photomultiplier (EMI type) installed and optical wedge re-calibrated. The original incandescent Standard Lamps (100 V AC) replaced by quartz halogen lamps (24 V DC). Instrument relocated to a new site at Churchill.

These events were significant since they created **three distinct historical periods** all of which exhibited different examples of SLT trends.

Period (1). 1960 to 1972. The instrument contained the original cemented optical wedge and used the original incandescent standard lamps.

Period (2). 1972 to 1979. The instrument contained the original optical wedge converted to the '**air-space' configuration** and used the original incandescent standard lamps.

Period (3). 1979 to 1989. The instrument contained the 'air-space' wedge, a new photomultiplier and used the quartz halogen standard lamps. Also, the instrument was housed in a new shelter.

Examples of SL Trends in Period (1)

From 1960 to 1972 the SLT R-values decreased steadily and non-uniformly versus wavelength resulting in **increasing positive** and **non-linear SLC's** and these features are shown in Table 2. The density gradient of the optical wedge was re-determined in 1963, 1964, 1967 and 1969 resulting in new R-N Tables. The SLC's were essentially zero (0.0) after each new set of R-N tables were established but became increasingly non-linear until the next wedge density gradient was re-established.

A similar but more extreme example occurred with D 59 (Resolute) in 1958/59 when the lamp test R-values lowered in a non-linear manner by 20.2, 18.6 and 16.0 respectively on A, C and D wavelengths during a period of **twenty-one months**. By comparison, the change with D 60 was much slower when the R-values lowered by about 14.8, 11.8 and 9.5 over a period of nearly **twelve years**. The problem with D 59 was attributed to a deterioration of the balsam cement which binds the quartz strips of the wedges resulting in a non-linear change to the light transmission capability of the wedge. The solution to the D 59 problem was the introduction of the 'air space' optical wedge which removes the balsam cement. The same corrective procedure was carried out in 1972 with D 60.

It is not known why the balsam cement begins to deteriorate but it is significant to note that both D 59 and D 60 were relatively new instruments (circa mid 1950's) when this happened. A similar event happened with D 77 after twenty years of use when the cement deterioration was visible as a 'feathering' effect in one section of the wedge. **Users of Dobson instruments containing original cemented optical wedges should be aware that this is a potential problem regardless of the age of the instrument.**

Table 2.

A Progressive and Non-linear Decrease of Standard Lamp Test R-values
Dobson No. 60, 1960 to 1972, Toronto and Churchill, Canada

	Lamp 60 B			Lamp 60 C			S.L. Corrections				
	R a	R c	R d	R a	R c	R d	A	C	D	AD	
Jul 1959	Optical wedge calibration										Toronto
Jul 1960	26.1	26.1	26.1	29.9	28.6	27.7	0.0	0.6	-0.1	0.1	
Jan 1961	25.3	25.5	25.7	29.1	28.0	27.4	0.8	1.2	0.3	0.5	
May 1961	24.7	25.2	25.5	28.5	27.7	27.1	1.4	1.5	0.5	0.9	
Jun 1961	** Overexposure of Photomultiplier ** (see later text)										
Jul 1961	24.6	25.0	25.1	29.2	28.0	27.2	1.2	1.5	0.7	0.5	
Jan 1962	22.5	23.1	24.0	27.0	26.3	26.0	3.4	3.4	1.9	1.5	
Jul 1962	21.9	22.7	23.6	26.4	25.8	25.5	4.1	3.9	2.4	1.7	
Jan 1963	21.2	22.3	23.2	25.7	25.3	25.0	4.8	4.4	2.9	1.9	
Jul 1963	20.5	21.6	22.7	25.1	24.8	24.6	5.5	5.0	3.3	2.2	
Nov 1963	Optical wedge calibration. New R-N tables										
Jan 1964	18.7	20.1	21.1	23.4	23.2	23.1	0.2	0.1	0.3	-0.1	
Jul 1964	18.5	20.1	21.2	23.1	23.1	23.2	0.5	0.2	0.2	0.3	
Dec 1964	Optical wedge calibration. New R-N tables										Churchill
Jan 1965	18.3	20.0	21.2	23.2	23.2	23.3	0.7	0.7	0.6	0.1	
Jul 1965	17.7	19.5	20.7	22.6	22.8	22.9	1.3	1.2	1.1	0.2	
Jan 1966	16.0	18.1	19.4	21.1	21.4	21.5	2.9	2.7	2.5	0.4	
Jul 1966	15.5	17.7	19.1	20.3	20.9	21.2	3.6	3.1	2.8	0.8	
Jan 1967	14.7	16.9	18.5	19.5	20.2	20.6	4.4	3.9	3.4	1.0	
Jul 1967	14.7	17.0	18.6	19.6	20.3	20.8	4.4	3.8	3.2	1.2	
Nov 1967	Optical wedge calibration. New R-N tables										
Jan 1968	15.1	17.8	19.7	19.9	21.0	21.8	0.1	0.1	-0.1	0.2	
Jul 1968	14.5	17.4	19.3	19.3	20.5	21.3	0.7	0.6	0.3	0.4	
Jan 1969	13.8	16.7	18.7	18.8	20.0	20.9	1.3	1.2	0.8	0.5	
Jun 1969	Optical wedge calibration. New R-N tables										
Jul 1969	15.6	17.9	19.3	19.0	20.5	20.9	0.0	0.0	0.0	0.0	
Jan 1970	13.0	15.8	17.8	18.2	18.5	19.3	1.7	1.5	1.6	0.1	
Jul 1970	12.4	15.2	17.2	17.1	18.3	19.2	2.5	2.4	2.0	0.5	
Jan 1971	11.6	14.7	16.9	16.6	17.9	19.0	3.2	2.9	2.2	1.0	
Jul 1971	11.2	14.3	16.6	16.0	17.4	18.5	3.7	3.4	2.6	1.1	
Jan 1972	10.9	14.1	16.5	15.9	17.3	18.4	3.9	3.6	2.7	1.2	
Apr 1972	10.7	14.0	16.4	15.7	17.2	18.4	4.1	3.7	2.8	1.3	
Delta R	**15.4**	**12.1**	**9.7**	**14.2**	**11.4**	**9.3**	**(July 1960 to April 1972)**				
Delta R	**13.9**	**11.0**	**8.7**	**13.5**	**10.8**	**8.8**	**(July 1961 to April 1972)**				

Examples of SL Trends in Period (2)

The D 60 standard lamp test results during Period (2) are listed in Table 3 and show that conversion to the 'air-space' optical wedge has eliminated the progressive and non-linear decrease of the R-values which existed in Period (1). It is noted that lamps 60 B and 60 E were used during Period (2) as opposed to the use of 60 B and 60 C during Period (1) but this does not influence the arguments which follow.

The important feature of the results in Table 3 is the slow **increase** of the R-values resulting in **increasing negative** SLC's, and the fact that the changes are quite **linear versus wavelength.** Some of the possible causes of progressively increasing Standard Lamp R-values are:

(a) Clouding of the optical surfaces inside the instrument due to moisture and fine dust particle deposition. The most obvious effect would be a change of the reflection coefficients of mirrors M1 and M2.

(b) Changing characteristics of the standard lamp filaments due to extended use.

(c) Changing photomultiplier response due to extended use.

The trend results in Table 3 were most likely caused by clouding of the optical surfaces. This argument is partially substantiated by the evidence in Figure 1 (Dobson 62) which demonstrates seasonal effects due to humidity at certain times of the year. In the case of D 60 the humidity effect was not seasonal but continued in a progressive manner. A later example dealing with Period (3) shows a reasonably stable set of SL R-values when D 60 was operated in a more controlled environment after it was moved to a new site.

The clouding process was most likely happening during Period (1) but the effect could not be detected in the SL R-values due to the continuous density gradient change within the optical wedge.

The incandescent standard lamps required a twenty minute warming period and were used twice monthly. Lamp 60 B was used for more than **twenty** years dating back to 1957, while lamps 60 C and 60 E were used for **fifteen** and **six** years respectively. It is not possible to effectively compare the **possible aging effects** with lamps **60 B and C** because they were used during Period (1) when the wedge density problem existed. The Ra, Rc and Rd values of Lamp 60 B were four to five R-units lower than the respective values of Lamp 60 C, therefore the test results were influenced differently by the wedge density change. However, a meaningful comparison is possible with lamps **60 B and E** during Period (2) after conversion to the 'air-space' wedge. It is noteworthy that over the period from May 1972 to October 1977 the lamps tracked each other in a consistent manner as evidenced by **Delta R** in Table 3, regardless of the fact that lamp 60 B had been in continuous use for twenty years as opposed to five years for lamp 60 E. The Delta R values of both lamps suggest a very small non-linear change versus wavelength.

It is difficult to identify standard lamp test changes which may be attributed to **changing photomultiplier response** over a long period of time. The changes shown in Table 3 are most likely not due to multiplier change. Furthermore, it is not known what types of changes might be expected such as increasing or decreasing R-values and if such changes would be linear or non-linear versus wavelength. However, details are given later of one particular incident involving the exposure of a multiplier to very strong light.

Examples of SL Trends in Period (3)

The SL history of Dobson 60 shows that there were no significant trends during Period (3) in contrast to the large positive and negative trends previously identified during Periods (1) and (2). Table 4 shows reasonably constant R-values over a period of ten years. Note the small **Delta R** values which are linear versus wavelength from September 1979 to December 1989 and compare these values with those in Tables 2 and 3.

There is no clear evidence of seasonal trends during Period (3) and this suggests that the new observatory provided a well controlled environment for Dobson 60. However, it is important to note that a humidification system was installed in the building to counteract a static electricity problem with the operation of the aerological computer equipment. It is possible that the added humidity in the observatory may have caused the slow increase of the SL R-values beginning in June 1988.

The **operational stability** of Dobson 60, as indicated by SL test results during Period (3), is largely attributed to the well controlled environment within the observatory. Other factors may have contributed to the stable performance such as the introduction of Quartz Halogen lamps and the installation of a new EMI photomultiplier in 1979. However, there are no known similar examples to prove this statement.

A Long-term Comparison of Quartz Halogen Standard Lamps

Dobson 60 was provided with four quartz lamps in 1979. Lamps 60 V and W were used twice monthly for more than ten years while lamps 60 X and Y were maintained as spares. The four lamps were periodically compared in order to identify possible changes in the characteristics of any one lamp. The **Delta R** values **(08/79 - 06/86)** listed below suggest that the characteristics of the well used lamps 60 V and W have changed slightly over seven years when compared with the infrequently used lamps 60 W and X.

	Lamp 60 V			Lamp 60 W			Lamp 60 X			Lamp 60 Y		
	R a	R c	R d	R a	R c	R d	R a	R c	R d	R a	R c	R d
08/79	28.3	29.0	29.4	28.2	28.7	29.3	28.3	29.0	29.5	28.2	28.9	29.4
09/79	28.7	29.2	29.6	28.4	28.9	29.3	28.9	29.4	29.9	28.8	29.3	29.8
05/80	29.1	29.5	30.1	28.5	29.2	29.7	29.5	29.9	30.3	29.2	29.8	30.3
12/81	28.6	29.0	29.5	27.9	28.6	29.0	28.8	29.2	29.7	28.7	29.2	29.6
02/86	28.5	28.9	29.3	28.1	28.6	28.9	28.7	29.3	29.6	28.8	29.3	29.6
06/86	28.5	29.0	29.4	28.0	28.5	28.9	28.9	29.3	29.5	28.7	29.3	29.5
Delta R	**-0.2**	**0.0**	**0.0**	**0.2**	**0.2**	**0.4**	**-0.6**	**-0.3**	**0.0**	**-0.5**	**-0.4**	**-0.1**

Table 3.

Standard Lamp Test R-values after conversion to 'Air-space' Optical Wedge
Dobson 60, Churchill, Canada

	Lamp 60 B			Lamp 60 E			S.L. Corrections			
	R a	R c	R d	R a	R c	R d	A	C	D	AD
05 1972	Optical Wedge calibration after 'air-space' conversion									
05 1972	32.0	30.7	30.3	28.7	28.4	28.4	0.0	0.0	0.0	0.0
06 1972	32.5	31.3	30.9	29.4	28.9	28.9	-0.6	-0.6	-0.6	0.0
08 1972	32.7	31.3	30.8	29.5	29.1	29.1	-0.8	-0.7	-0.6	-0.2
10 1972	33.0	32.1	31.5	29.8	29.8	29.8	-1.1	-1.4	-1.2	0.1
12 1972	33.0	32.3	31.5	29.9	29.9	29.9	-1.2	-1.6	-1.4	0.2
02 1973	33.2	32.4	31.6	30.1	30.1	29.9	-1.4	-1.7	-1.4	0.0
04 1973	33.6	32.7	32.0	30.5	30.4	30.2	-1.8	-2.0	-1.7	-0.1
06 1973	33.9	32.7	32.0	30.8	30.5	30.4	-2.1	-2.1	-1.9	-0.2
08 1973	34.1	33.0	32.3	31.1	30.9	30.6	-2.3	-2.4	-2.1	-0.2
10 1973	34.3	33.2	32.7	31.3	31.0	31.0	-2.5	-2.5	-2.5	0.0
	Optical wedge calibration. New R-N tables.									
10 1973	34.4	32.9	32.3	31.6	30.9	30.9	-0.1	0.0	-0.1	0.0
12 1973	35.2	33.7	33.1	32.2	31.7	31.7	-0.8	-0.8	-0.8	0.0
02 1974	35.3	33.7	33.1	32.3	31.6	31.6	-0.8	-0.8	-0.8	0.0
04 1974	35.3	33.7	32.9	32.1	31.3	31.2	-0.7	-0.7	-0.6	-0.1
06 1974	35.1	33.5	32.9	32.0	31.2	31.1	-0.6	-0.5	-0.4	-0.2
08 1974	34.9	33.3	32.7	31.8	31.1	31.1	-0.4	-0.4	-0.4	0.0
10 1974	34.9	33.4	32.8	31.9	31.1	31.1	-0.5	-0.4	-0.5	0.0
12 1974	35.1	33.6	32.9	32.0	31.4	31.3	-0.6	-0.6	-0.6	0.0
02 1975	35.5	33.8	33.2	32.4	31.7	31.6	-1.0	-0.8	-0.9	-0.1
04 1975	35.6	34.0	33.5	32.6	31.9	31.9	-1.2	-1.1	-1.1	-0.1
06 1975	35.4	33.9	33.4	32.4	31.8	31.9	-1.0	-0.9	-1.1	0.0
08 1975	35.3	33.8	33.2	32.1	31.5	31.5	-0.8	-0.7	-0.8	0.0
10 1975	35.7	34.1	33.4	32.6	32.0	31.8	-1.2	-1.1	-1.1	-0.1
12 1975	35.4	33.9	33.3	32.4	31.7	31.6	-1.0	-0.9	-0.9	-0.1
02 1976	35.9	34.4	33.8	32.8	32.0	32.0	-1.4	-1.3	-1.4	0.0
04 1976	35.6	34.2	33.5	32.6	32.0	31.8	-1.2	-1.2	-1.1	-0.1
06 1976	36.5	35.1	34.4	33.5	32.8	32.8	-2.0	-2.0	-2.0	0.0
08 1976	36.4	35.1	34.3	33.2	32.7	32.7	-1.9	-2.0	-1.9	-0.1
10 1976	35.9	34.8	33.9	32.8	32.3	32.4	-1.5	-1.5	-1.5	0.0
12 1976	35.1	33.7	33.3	32.1	31.4	31.5	-0.6	-0.7	-0.9	0.3
01 1977	Optical wedge cleaned									
02 1977	36.3	34.9	34.4	33.1	32.5	32.7	-1.8	-1.7	-2.0	0.2
04 1977	36.6	35.0	34.4	33.2	32.6	32.8	-2.0	-1.9	-2.0	-0.2
06 1977	36.8	35.1	34.6	33.7	32.9	33.0	-2.3	-2.0	-2.2	-0.1
08 1977	37.1	35.4	34.7	33.8	33.1	33.1	-2.5	-2.3	-2.3	-0.2
10 1977	36.8	35.3	34.8	33.8	33.0	33.1	-2.3	-2.2	-2.3	0.0
Delta R	**-4.8**	**-4.6**	**-4.5**	**-5.1**	**-4.6**	**-4.7**	**(May 1972-Oct 1977)**			

Table 4.

Standard Lamp R-Values with Quartz Halogen Lamps and New Photomultiplier After Dobson 60 Re-located to a New Site at Churchill, Canada

	Lamp 60 V			Lamp 60 W			S.L. Corrections				
	R a	R c	R d	R a	R c	R d	A	C	D	AD	
08 1979	28.3	29.0	29.4	28.2	28.7	29.3	0.0	0.0	0.0	0.0	Toronto
09 1979	28.7	29.2	29.6	28.4	28.9	29.3	-0.3	-0.2	-0.1	-0.2	Churchill
12 1979	29.0	29.6	30.0	28.7	29.3	29.6	-0.6	-0.6	-0.5	-0.1	
05 1980	29.1	29.5	30.1	28.5	29.2	29.7	-0.6	-0.5	-0.6	0.0	
09 1980	29.3	29.8	30.3	28.8	29.5	30.0	-0.8	-0.8	-0.8	0.0	
12 1980	28.9	29.3	29.7	28.3	28.9	29.3	-0.3	-0.3	-0.2	-0.1	
05 1981	28.4	28.7	29.2	27.8	28.5	28.7	0.2	0.3	0.4	-0.2	
12 1981	28.6	29.0	29.5	27.9	28.6	29.0	0.0	0.0	0.1	-0.1	
04 1982	28.6	29.0	29.4	28.1	28.5	29.0	-0.1	0.1	0.2	-0.3	
08 1982	29.0	29.3	29.7	28.5	28.8	29.2	-0.5	-0.2	-0.1	-0.4	
12 1982	29.1	29.5	29.9	28.5	29.0	29.4	-0.6	-0.4	-0.3	-0.3	
04 1983	28.9	29.3	29.6	28.4	28.8	29.1	-0.4	-0.2	0.0	-0.4	
08 1983	28.8	29.3	29.6	28.3	28.8	29.2	-0.4	-0.3	-0.1	-0.3	
12 1983	28.5	28.9	29.3	28.1	28.5	28.9	0.0	0.1	0.2	-0.2	
04 1984	28.5	28.9	29.3	27.9	28.3	28.7	0.1	0.3	0.4	-0.3	
08 1984	28.4	28.8	29.2	28.0	28.4	28.7	0.1	0.2	0.3	-0.2	
12 1984	28.5	28.9	29.2	28.0	28.3	28.8	0.0	0.2	0.3	-0.3	
04 1985	28.7	29.1	29.4	28.1	28.5	28.9	-0.1	0.0	0.2	-0.3	
08 1985	28.5	29.0	29.4	28.0	28.5	28.9	0.0	0.1	0.2	-0.2	
12 1985	28.5	29.0	29.4	28.1	28.5	28.9	0.0	0.1	0.2	-0.2	
02 1986	28.5	28.9	29.3	28.1	28.6	28.9	0.0	0.1	0.2	-0.2	
04 1986	28.6	29.1	29.5	28.2	28.6	29.0	-0.1	0.0	0.2	-0.3	
06 1986	28.5	29.0	29.4	28.0	28.5	28.9	0.1	0.1	0.3	-0.2	
08 1986	28.5	29.1	29.4	27.9	28.5	28.7	0.1	0.1	0.3	-0.2	
12 1986	28.6	29.1	29.4	28.1	28.5	29.0	0.0	0.0	0.1	-0.1	
03 1987	28.6	29.0	29.4	28.0	28.6	28.9	0.1	0.0	0.2	-0.1	
07 1987	28.5	29.1	29.5	28.1	28.7	29.0	0.1	0.1	0.2	-0.2	
11 1987	28.4	29.0	29.4	27.9	28.6	28.8	0.1	0.1	0.3	-0.2	
03 1988	28.3	28.9	29.3	27.7	28.4	28.7	0.3	0.2	0.4	-0.1	
06 1988	28.4	29.0	29.1	27.6	28.3	28.6	0.3	0.2	0.5	-0.2	*
08 1988	28.9	29.5	29.6	28.3	28.6	29.3	-0.3	-0.3	-0.2	-0.1	
12 1988	29.7	30.1	30.7	29.1	29.7	30.2	-1.1	-1.1	-1.1	0.0	
04 1989	29.9	30.4	30.8	29.1	29.8	30.2	-1.2	-1.2	-1.1	-0.1	
08 1989	29.7	30.2	30.7	29.3	29.8	30.1	-1.2	-1.1	-1.1	-0.1	
12 1989	29.5	30.3	30.8	29.5	29.9	30.2	-1.2	-1.2	-1.2	0.0	Churchill
Delta R	**-0.8**	**-1.1**	**-1.2**	**-1.1**	**-1.0**	**-0.9**	**(Sept 1979 to Dec 1989)**				

***** Humidification system installed in building to counteract static electricity problems with the aerological computer equipment.

The Effect on SL R-values due to Overexposure of the Photomultiplier.

In June 1961 the photomultiplier of Dobson 60 was inadvertently exposed to very strong light when a student observer attempted to make a Focused Sun observation at airmass 1.2. The first evidence of instrument damage was the micro-ammeter needle which essentially was reduced to a 'small twisted mess'. The instrument was immediately very insensitive and subsequent SL tests revealed major R-value changes which were attributed to photomultiplier damage. The instrument response improved over a number of days and this was evidenced by a gradual restoration of the SL R-values as follows:-

Test Date	Test #	Lamp 60 B				Lamp 60 C				Delta R Lamp B - Lamp C			
		R a	R c	R d	R c'	R a	R c	R d	R c'	A	C	D	C'
18 05	(1)	24.7	25.2	25.5	81.4	28.5	27.7	27.1	80.8	-3.8	-2.5	-1.6	0.6
16 06		**overexposure of photomultiplier**											
16 06	(2)	18.4	18.8	18.9	91.7	23.0	21.4	20.6	90.2	-4.6	-2.6	-1.7	1.5
21 06	(3)	18.0	17.7	17.4	98.0	22.4	20.9	20.1	95.8	-4.4	-3.2	-2.7	2.2
22 06	(4)	20.8	21.0	21.0	82.1	25.7	24.3	23.3	79.5	-4.9	-3.3	-2.3	2.6
25 06	(5)	22.5	22.1	22.0	82.6	26.0	24.6	23.8	80.7	-3.5	-2.5	-1.8	1.9
28 06	(6)	24.4	24.6	24.7	82.0	29.2	27.8	27.1	80.2	-4.8	-3.2	-2.4	1.8
07 07	(7)	24.5	24.8	25.0	84.0	29.1	27.9	27.0	83.0	-4.6	-3.1	-2.0	1.0
17 07	(8)	24.8	25.1	25.2	87.4	29.4	28.1	27.3	86.3	-4.6	-3.0	-2.1	1.1
Delta R	(1-2)	**6.3**	**6.4**	**6.6**	**-10.3**	**5.5**	**6.3**	**6.5**	**-9.4**	**Initial Difference**			
Delta R	(8-2)	**6.4**	**6.3**	**6.3**	**-4.3**	**6.4**	**6.7**	**6.7**	**-3.9**	**Recovery Diff.**			
Delta R	(1-8)	**-0.1**	**0.1**	**0.3**	**-6.0**	**-0.9**	**-0.4**	**-0.2**	**-5.5**	**Total Difference**			

The above set of R-values reveal several interesting details regarding the overexposure of D 60 photomultiplier to excessive light.

(1) The relative sensitivity of the photocathode was changed with respect to the two wavelengths of a pair (i.e. S2/S3). In this case, the response change of the A, C and D pairs was reasonably uniform as evidenced by **Delta R (1-2)** although the values suggest a small non-linear wavelength change, especially with Lamp 60 C.

(2) The stabilization and recovery of the photomultiplier required **one month** as evidenced by **Delta R (8-2)** and this suggests that the photocathode had suffered considerable damage.

(3) At the end of the recovery period the R-values of Lamp 60 B compared very favourably with the values before the photomultiplier was overexposed but the comparable values with Lamp 60 C were less favourable as evidenced by **Delta R (1-8).**

This suggests that the damage was not uniform over the surface of the photocathode and that the energy from Lamp 60 C was concentrated on a slightly different part of the photocathode surface. Past experience with incandescent lamps such as 60 B and C showed that it was always difficult to find the optimum positioning of the lamp filament above the inlet window and the GQP whenever a new lamp was put into use.

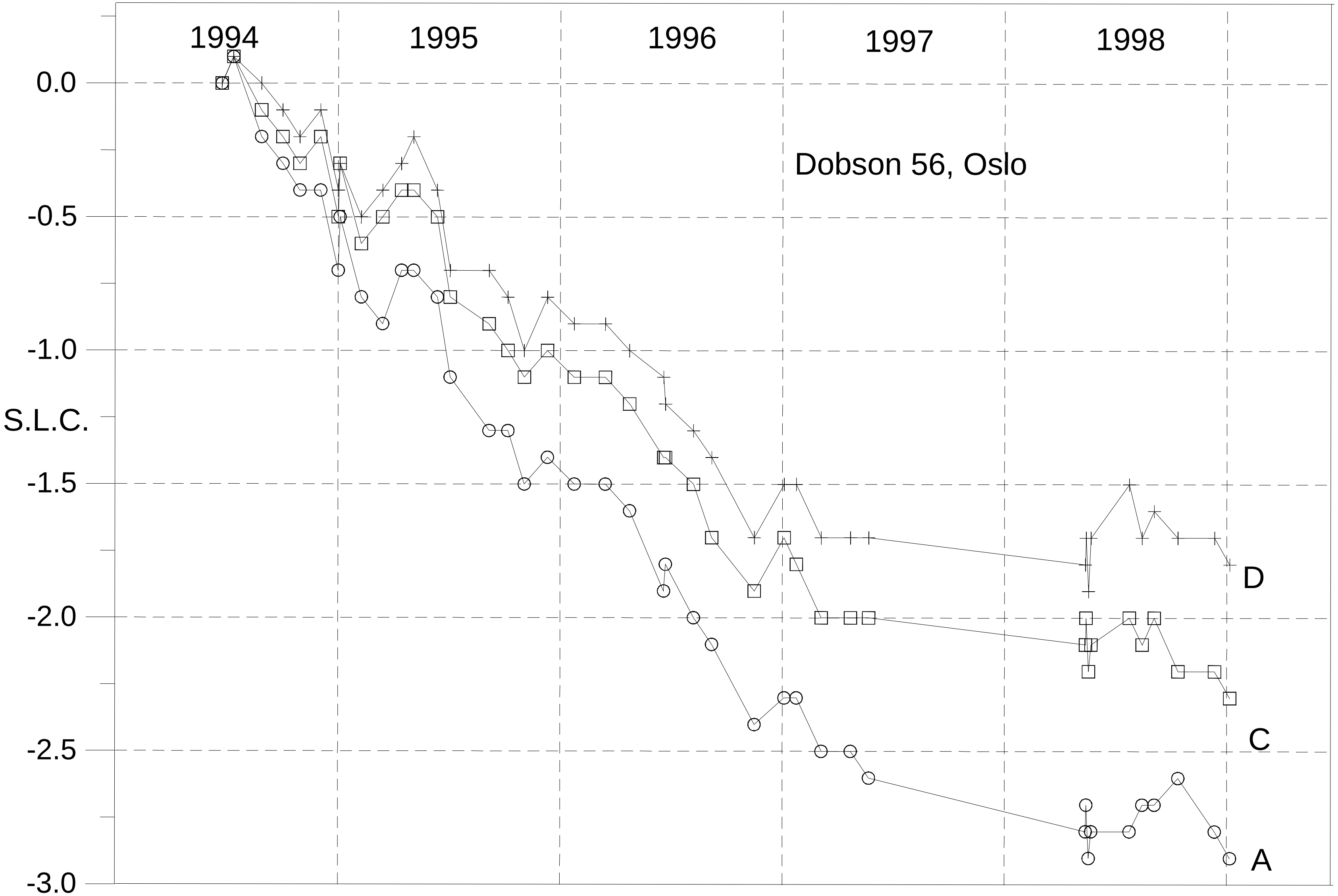

Figure 2. Non-linear Trend of Standard Lamp Corrections

SLT Trends most likely due to changing characteristics of the UV Cobalt filter at S5.

This is an example of the characteristics in Category (3) whereby the SLT R-values **increase** in a **non-uniform manner versus wavelength.** The data used in this example originate from the recent SLT history of Dobson 56 which has been in operational use at Oslo, Norway for several decades.

In June 1994 Dobson 56 attended the WMO Dobson Intercomparison at Izana, Spain where the instrument was compared with the world secondary reference standard instrument Dobson 65. The initial intercomparison results showed that the calibration level of D 56 had essentially remained unchanged in eight years and the Hg lamp tests indicated no requirement to make any optical adjustments. The density gradient of the optical wedge was re-established, new R-N Tables were provided based upon further intercomparison against the reference instrument and D 56 then returned to Oslo.

Figure 2 shows a plot of SL corrections for wavelength A, C and D from lamp 56Q3 beginning in June 1994 and ending in January 1999. The plot of June 1994 represent a correction of 0.0 determined during the final intercomparison at Izana. The remaining values stem from periodic lamp tests at the Oslo observatory after June 1994. A similar set of data exists for Lamp 56Q2 and shows the same trend characteristics as that of Lamp 56Q3.

For several years prior to June 1994 the SLT history of D 56 had shown minor variations from month to month but without evidence of trends or non-linear wavelength changes. The **non-linear wavelength trends** depicted in Figure 2 **began immediately after D 56 returned to Oslo from Izana.**

The maintenance of D 56 was given special attention after June 1994 when the non-linear SLT trend became evident (personal correspondence Univ. Oslo / Asbridge). Precise maintenance procedures were being followed, in particular the frequent replacement of the silica gel drying desiccant. Furthermore, a new 'drying' procedure was installed In December 1996 based upon a system used by the NOAA Laboratory, Boulder, USA. The 'drying' equipment is mounted on the outside of the instrument and comprises a low-pressure air pump which pulls air through a large desiccant tube and pumps the 'dry' air into the instrument. An advantage of the system is the continuous replenishment of 'dry' air within the spectrophotometer and being able to immediately recognize when to replenish the silica gel in the desiccant tube.

The trend of the D 56 SL corrections slowed after the new drying system was installed in December 1996 but the non-linearity continued. The UV cobalt filter behind slit S5 was inspected in March 1999 and revealed **a discolouring of the filter surface,** similar to the appearance of an oxidization condition.

The most likely cause of the non-linear SLT trends experienced with D 56 after July 1994 is the discolouring of the UV filter at slit S5. The reason for the sudden change is not fully understood but could possibly be attributed to the extreme environmental change which D 56 experienced at Izana in June 1994. For several days the instrument was exposed to many hours of intense heating in a very dry atmosphere. This is in contrast to Oslo where, under day to day operation throughout the year, the instrument is exposed to small temperature variations **but is always subjected to a moderately high level of humidity both inside the shelter and on the outdoor observing platform.** It would appear that D 56 experienced a severe 'drying out' process at Izana which triggered a change in the characteristics of the UV filter at S5.

Discolouring of the UV filter has been previously identified in other spectrophotometers but, to the authors's knowledge, the effects have not been documented. Attempts have been made to re-polish the filter surface but with limited success. The obvious remedial action is to replace the UV filter but this procedure is only recommended as a last resort (personal correspondence R. Evans/Asbridge) since a new filter may drastically change the test position of the SL by as much as 100 R-dial units.

The ideal time to carry out remedial action is when the instrument in question can be inter-compared against a reference standard. In the case of D 56, this will be attempted at an intercomparison of Dobson instruments.

Appendix C

Hysteresis Problems and Non-uniform Temperature Coefficients

Introduction

One of the most important requirements when making observations with the Dobson spectrophotometer is the precise setting of the Q1 wavelength selector lever to ensure that the desired wavelengths are falling in the focal plane at slits S2, S3 and S4. In this regard, each instrument is provided with a table of wavelength settings of Q1 which gives the required lever settings according to instrument temperature.

Establishment of the Q Table depends upon knowing the temperature coefficient of the Hg line 3129.6 AU. Therefore, it is important to occasionally verify the existing temperature coefficient value. In particular, verification should be done whenever major optical adjustments have been carried out involving the mirrors M1 and M2, especially when the mirror mounts have been disassembled to install new mirrors.

In order to understand the hysteresis problem it is necessary to understand the physical configuration of the mirror mount. Each mirror is mounted in a finely machined circular trough which has a precise diameter and depth. A circular leaf spring with a slightly smaller diameter is placed in the bottom of the trough and the mirror is placed on top of the leaf spring. A circular retaining ring is attached to the front of the mount by three small machine screws and holds the mirror in place. The diameter of the mirror is about 0.5 mm smaller than the trough diameter, therefore there is very little capability of lateral mirror movement within the trough. The thickness of the mirror combined with the strength of the leaf spring ensures that the mirror is firmly held in the vertical plane of the mirror trough. However, the tension provided by the leaf spring should not be so severe that it prevents a uniform reaction to expansion and contraction when the instrument is subjected to extreme temperatures. The possibility of hysteresis exists when the mirror and leaf spring are not reacting uniformly to temperature changes. Perhaps the leaf spring is not providing uniform pressure on the back surface of the mirror, or perhaps one portion of the mirror circumference is rubbing against the wall of the circular mount.

Further text will describe **two** examples of **hysteresis problems** within the mirror mount and **one** example of **differing temperature coefficients** between the Q1 and Q2 sides of a spectrophotometer. For the sake of this text, **hysteresis** may be described as a **reluctance to behave in an expected manner.**

Hysteresis Problem #1

A significant example of a hysteresis problem happened with Dobson 60 in 1964 at AES Canada when the instrument was being prepared for installation at Churchill. New mirrors were installed in the M1 and M2 mounts after which D 60 was subjected to a series of Hg Lamp Tests (3129.6 AU at slit S2) over a wide range of instrument temperature in order to verify the existing temperature coefficient.
Figure 1 illustrates a series of Hg tests of Q1 S2 and Q2 S2 immediately after new mirrors were installed. The instrument was slowly warmed from **1 to 33 C.** (Day 1) and

cooled from **37 to 24 C.,** (Day 2). The temperature coefficient line applicable to the existing Q Table (0.167/deg. C.) is also shown.

The tests of Day 1 and Day 2 revealed several very unusual features as follows:-

(1) While the instrument was **warming** the Q1 S2 values were larger by about **1 deg. of Q** than the corresponding **cooling** values in the region where the curves overlap between **24 and 33 deg. C.**.

(2) The Q1 'warming' curve from **1 to 26 deg. C** on Day 1 shows a temperature coefficient of about 0.07, **but changes to a negative** coefficient from **26 to 33 deg. C.**
The Q1 'cooling' curve on Day 2 shows a very indefinite shape which changes from a positive to a negative coefficient **at about 29 deg. C.**

(3) The Q2 S2 test values produce a satisfactory curve, the slope of which is in general agreement with the temperature coefficient line (0.167/1deg. C) although, the 'warming' values from **1 to 11 degrees** suggest that there was a temperature imbalance between the Q1 and Q2 ends of the instrument. The important feature of the Q2 curve is the good agreement between the 'warming' and 'cooling' values in the overlapping temperature region from **24 to 33 deg. C.**

The warming and cooling tests were repeated and produced results similar to Figure 1 except that the Q1 curve changed from a positive to a negative slope at various instrument temperatures between **21 and 26 deg. C.** The curve of Q2 S2 maintained a satisfactory slope with the warming and cooling test values agreeing where the curves overlapped.

The Q1 S2 test results indicated that a hysteresis problem existed in the circular M1 mirror mount of D60. In order to prove this the D60 mirror mount, complete with the new mirror, was removed from D60 and replaced by the same complete assembly from D77. (**Note: To avoid any misunderstanding, the circular mirror mount is attached by three machined bolts to the large L-bracket which is attached to the long optical frame of the instrument).**

The Q1 and Q2 S2 tests were repeated, both warming and cooling, using the complete circular mirror assembly of D77. The resulting Q1 S2 curve showed no discontinuity from about **6 to 41 deg. C.** This proved that the circular M1 assembly of D60 was at fault.

The next step in the process was to determine which component(s) was causing the problem within the M1 mount of instrument D60. Various combinations of the components from both D60 and D77 were used including the **circular leaf spring** which is located behind the mirror. Each combination was subjected to the warming and cooling Hg tests of Q1 S2 as follows:

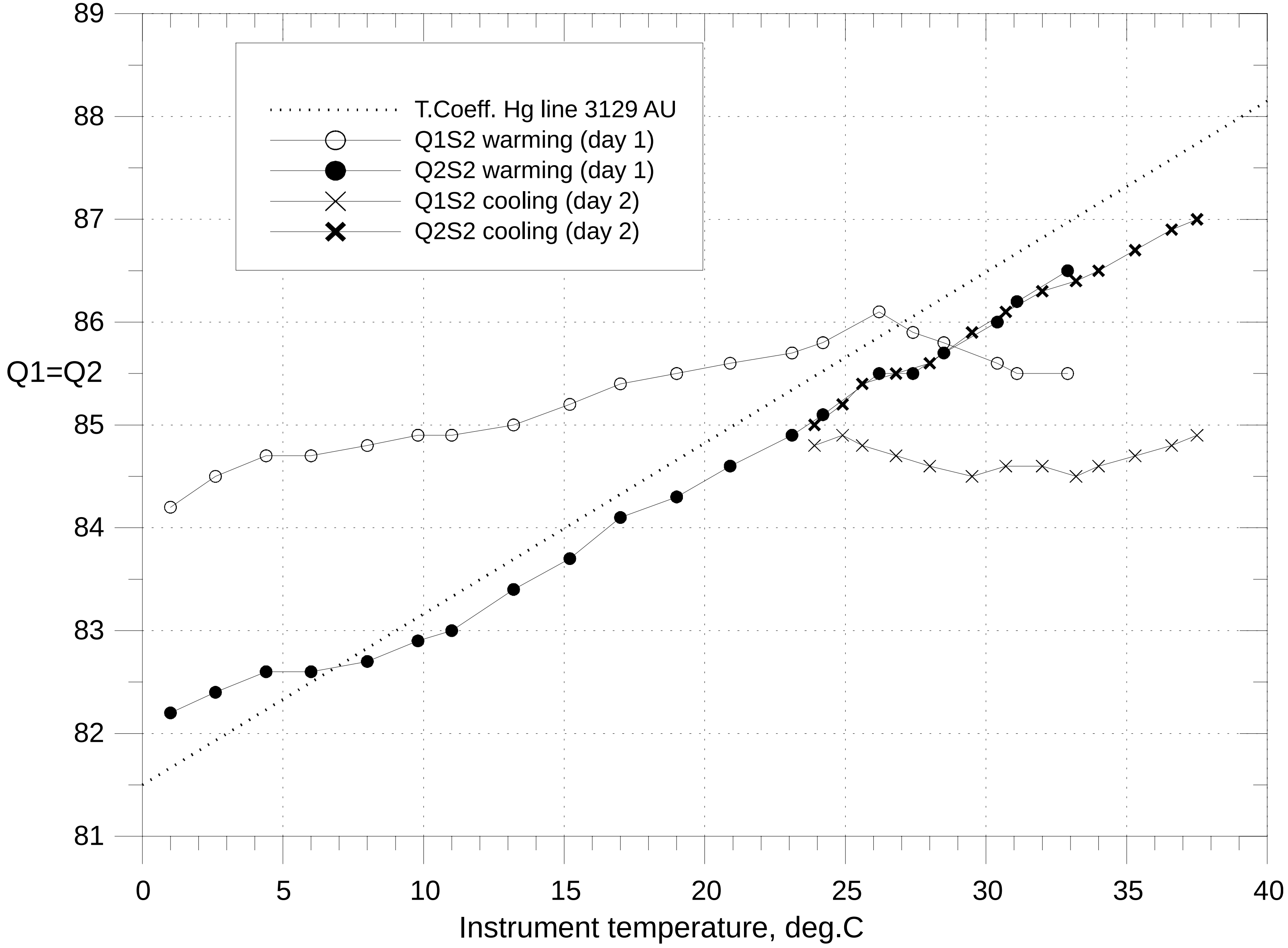

Figure 1. A Problem of Hysteresis in M1 mirror mount.

Component Combinations	Results of Q1 S2 Hg Tests
(i) **D60 mirror** in **D77 mount** with **D77 leaf spring.**	Satisfactory.
(ii) **D60 mirror** in **D77 mount** with **D60 leaf spring.**	Unsatisfactory.
(iii) **D77 mirror** in **D60 mount** with **D60 leaf spring.**	Unsatisfactory.
(iv) **D60 mirror** in **D60 mount** with **D77 leaf spring.**	Satisfactory.

Unsatisfactory test results occurred when the **D60 leaf spring** was used in combination with other components. This is difficult to understand since the history of D60 from 1957 to 1964 had not demonstrated this problem. The hysteresis problem began when the **new mirror** was placed in the M1 mount and it appears that the combination of the new mirror with the **original leaf spring** would not allow a uniform reaction to extreme temperature changes within the circular mount.

D60 was restored to operational capability in 1964 using the leaf spring from D77. It is worthy to note that the temperature coefficient of the Hg line 3129 AU (S2) changed to 0.15 deg. Q/deg. C. as opposed to the previous value of 0.167. As a matter of interest, the original leaf spring of D60 was installed in the D77 mirror mount in 1964 and the instrument has operated without problems since then.

The intent of the above text has been to draw attention to the possibility of what may happen when an instrument has undergone the replacement or adjustment of any optical component, especially mirrors M1 and M2. It is important to verify the temperature coefficient of the Hg line 3129 AU after the optical changes have been made. Although the hysteresis problem was eliminated, it was not possible to completely identify the fault which was created by inserting the new mirror. It is possible that the leaf spring was inadvertently distorted thus changing the overall tension of the spring causing a non-uniform pressure on the back surface of the mirror. This would cause one segment of the mirror edge to be pushed against the inner wall of the circular mount and not allow a uniform reaction to instrument temperature changes.

Hysteresis Problem #2

The second hysteresis problem is similar to the first since it involves the mirror mounts. However, the cause of hysteresis problem #2 involves transporting an instrument from one location to another as may happen during the process of inter-comparing Dobson spectrophotometers.

When a Dobson spectrophotometer is transported from one location to another there is always the possibility that the instrument may suffer physical shock no matter how much protection has been provided to prevent this possibility. A severe physical shock may disturb the optical alignment of the instrument. Therefore, when a Dobson arrives at a new location, one of the first requirements is to determine the optical alignment status of the instrument by performing tests of Q1 S2 and Q2 S2 (HG line 3129.6 AU.) and comparing the results with the existing Table of Q1 settings.

There are **two different scenarios** to consider when comparing the test results with the Table of Q1 settings.

Scenario #1. When an instrument has been moved to a location which is essentially at the **same altitude above sea level** as the previous location, the Q1 S2 test results should agree with the Table of Q1 settings by **about +/- 0.1 deg. of Q** provided that the instrument has not suffered physical shock. It is suggested that the Hg test be repeated several times **over a 10 to 15 degree temperature range**. A graphic plot of the Q1 S2 tests values versus temperature should produce a reasonably linear curve with a slope equivalent to the existing temperature coefficient of the Hg line 3129 AU.

If the curve is non-linear then there may be a hysteresis problem within the mirror mount. A simple remedy may be attempted using the butt end of a screwdriver and gently tapping the L-bracket on which the mirror mount is attached. The tapping should be done near the centre of the back side of the L-bracket. **But do not use excessive force since this may disturb the L-bracket with respect to the position where it is held on the long optical frame of the instrument.**

It is important to perform the Hg test of Q1 S2 **before** and **after** tapping the L-bracket in order to identify and changes. Further tests should be done over a temperature range as suggested previously in order to determine linearity.

Scenario #2. When an instrument has been moved to a location at a **significantly different altitude above sea level,** either higher or lower than the original location, the Q1 S2 test results will not agree with the existing Table of Q1 settings since the refractive index of quartz changes with pressure. The general guideline (dated circa 1957) is that Q1 S2 test values should reduce by **0.5 deg. Q/100 mb pressure decrease.** This criterion should be regarded as an approximation since it is probably based upon the average of a few instruments.

On arrival at the new location, the same Hg test procedures must be carried out as in Scenario #1. It will be necessary to establish a new Table of Q1 settings for use at the different altitude. It is important to do tests of Q1 S2 over a good temperature range to verify that a hysteresis problem does not exist. Remedial action, if needed, may be carried out as previously described.

Differing Temperature Coefficients between the Q1 and Q2 sides of a Dobson.

A spectrophotometer with well adjusted optics will produce Hg test values of Q1 S2 and Q2 S2 which agree within **+/- 0.5 degrees** and this agreement will hold true over a wide range of instrument temperature. This means that a temperature coefficient value produced by the Q2 S2 test values will be very similar to the coefficient value produced by the Q1 S2 test values of the Hg line 3129 AU. However, the calibration and optical adjustment history of Dobson 59 (Resolute, Canada 1957 to 1989) clearly demonstrates an exception to the above statement. The Hg tests of Q1 S2 (3129 AU) have consistently produced a temperature coefficient of **0.18 deg. Q/deg. C** while the tests of Q2 S2 have shown a value of **0.08 deg. Q/deg. C.**

It is difficult to identify the reason for the different coefficients between the Q1 and Q2 sides of the instrument **but it possible to eliminate some of the reasons** based upon the major adjustments to D 59 during the period of 32 years as follows:

(1) Replacement of the optical wedge in 1959 (see Appendix C). The light path involving the optical wedge is limited to light which passes through slit S3. Therefore, replacement of the optical wedge has no influence upon the determination of the temperature coefficient of the Hg line 3129 AU which is based upon tests of Q1 S2 using light which falls on and passes through slit S2.

(2) **Replacement of mirrors M1 and M2 with newly coated mirrors in 1979, also replacement of the original IP28 photomultiplier with the more sensitive EMI multiplier.** The effective result of the above instrument changes was to create a temperature coefficient of **0.19 deg. Q/deg. C.** on the Q1 side of the instrument as opposed to the former value of **0.18,** while the coefficient on the Q2 side of the instrument remained unchanged at **0.08.** The above results suggest that the replacement of the mirrors and the photomultiplier had very minimal or no effect on the temperature coefficient values.

(3) During the 32 years of operation there was no evidence of hysteresis in the mirror mounts as was described in the problems with D 60.

One possible reason for the different temperature coefficients between the Q1 and Q2 sides of D 59 concerns prisms **P1 and P2.** It is well known that the temperature coefficient value varies from instrument to instrument and is most likely due to the **refractive characteristics of each individual quartz prism.** Therefore, it is possible that prisms P1 and P2 in D 59 have very different refractive characteristics.

A second possible reason concerns **the expansion and contraction characteristics of the Hiduminium alloy** which is used in the manufacture of Dobson instruments. Hiduminium has very uniform properties of expansion and contraction but it is possible there may be a flaw in the casting of the long frame of D 59 on which most of the optical components are mounted.

The above text demonstrates **one known example** of significantly different temperature coefficients between the Q1 and Q2 sides of a Dobson instrument. But It is emphasized that the operational capability of D 59 is not affected by this feature, since the Q2 settings of wavelengths A, C and D are always set to the tabled value for 15 degrees.

Appendix D

Two types of Mu Dependence, their causes and suggested corrective measures.

Introduction

Any discussion using the term 'mu dependence' usually results in some degree of confusion since it is not always understood that the expression may be describing two different effects in the measurement of total column ozone with the Dobson spectrophotometer. Mu dependence is always associated with various trends of total ozone values which are revealed by DSGQP measurements over a range of mu from high sun to low sun (mu 1 to 3 or greater) or vice-versa. Such trends are easily identified when a suspect instrument is inter-compared against an instrument of known calibration accuracy during a half-day of measurements, but may also be identified without reference to another instrument when the ozone values exhibit consistent trends from high sun to low sun or vice-versa. The following text identifies the various trends and their possible causes and, where possible, suggests remedial action to eliminate or reduce the mu dependence effect.

Mu dependence due to errors in the Extra-Terrestrial Constants (ETCs).

This type of mu dependence is characterized by ozone values which, on a day to day basis, show a consistent straight-line trend from high sun to low sun and a reversal of the trend from low sun to high sun. It is assumed, of course, that ozone remains relatively constant for any given day. Such trends are more easily identified when a questionable instrument is inter-compared against a reference instrument of known calibration accuracy but may be identified without a reference instrument when the questionable instrument shows ozone values which are consistently different from high sun to low sun or vice-versa.

The positive or negative trend of ozone values from high sun to low sun depends upon the positive or negative error of the extra-terrestrial constant. For example, an instrument which consistently produces larger ozone values at mu 1.2 than at mu 3.0 suggests that the measured differences of Na-Nd (or Nc-Nd) are too large. The reverse is true when the ozone values are larger at mu 3 than at mu 1.2.

The ETCs of a questionable instrument are normally corrected by comparison against a reference spectrophotometer.

Mu dependence identified by a 'roll-off' of ozone values from High Sun to Low Sun.

The most common conception is that a mu dependent Dobson instrument exhibits an exponential roll-off effect (decreasing ozone values) when a series of AD or CD DSGQP measurements are made from about mu 2.5 to 4.0 or greater. **This type of mu dependence exists with all instruments** but the roll-off effect may begin at different mu values for each instrument and for different reasons which will be described. The reason for the roll-off effect may be attributed to two reasons, namely:

(i) Pick-up of forward scattered light by the sun director prism.

The sun director prism picks up forward scattered light from the outer fringes of the sun's disc. The unwanted light component does not present a problem at high sun but the effect can be seen as a roll-off of the ozone values beginning at about mu 2.5 or greater depending upon the clarity of the atmosphere. The unwanted component increases the radiation passing at slit S2 and influences the relative intensity of the S2/S3 wavelength pair causing a lower R-dial value than would be achieved without the unwanted light component. The effect is most pronounced on the A wavelength pair and the end result is a value of Na-Nd which is too small and a corresponding low value of total column ozone.

Varying degrees of ozone roll-off due to forward scattered light may be witnessed by making a series of measurements during clear blue sky conditions (e.g. after the passage of a cold front) and again during hazy sky conditions. The roll-off effect will begin at a larger mu value when the atmosphere is relatively free of haze. A similar comparison may be made by making a series of measurements near sea level (e.g. Toronto, 0.2 km) and again at altitude (e.g. Mauna Loa, 3.4 km). Under reasonably clear sky conditions at Toronto the roll-off effect with D 77 begins at about mu 3.2 but is barely evident at mu 4.0 under the reduced atmospheric conditions of Mauna Loa.

(ii) Stray light within the instrument.

During the process of cleaning the optics of D 18 (Toronto), lens L1 was accidently inverted. The result of this mistake not only created a very severe roll-off of ozone values beginning at mu 2.1 but also produced a large number of scattered values. This condition had not previously existed with D 18. In searching for the cause of this problem the instrument was placed in a darkroom with the top cover removed and the Hg lamp positioned at the inlet window (without the GQP). An auxiliary Q block at slit S1 allowed the strong Hg Line 4358 AU to fall on the vertical plane at slit S4. In the darkened room it was possible to detect 'flare spots' by vertically moving a flattened piece of wire through the optical path between L1 and S4. The inverted lens L1 was correctly repositioned and the severe roll-off problem disappeared.

Even though the 'flare spots' were discovered when lens L1 was in an inverted position, it led to the belief that the phenomenon could also exist in instruments with a correctly positioned lens and could possibly be contributing to stray light. More significant was the possibility that the flare spots could be in the optical path between L1 and slit S2 which would allow unwanted radiation to pass S2. This would have the same effect on the relative intensity of the S2/S3 wavelength pair as previously described. The immediate challenge in 1978 was to devise a method of optical adjustment which would remove, or at least reduce, the possible effects of 'flare spots' in the optical path between lens L1 and slit S2. The first suggested adjustment (Olafson) was to rotate the L1 holding bracket by a very small amount in a counter-clockwise (c/cw) direction and the method proved to be successful.

In August 1978 Dobson 40 had been sent to AES Canada for standardization. The results of an initial intercomparison of D 40 against D 77 using the DSGQP method are illustrated in Figure 1 (top section) and show ozone values from the **A wavelength pair** over the mu range 2.1 to 3.8 observed under a relatively haze-free sky condition.

The results clearly indicate a lowering of D 40 ozone values beginning at about mu 2.5 and extending to a severe roll-off at large airmass. A c/cw adjustment was made to lens L1 of D 40 and the intercomparison was repeated with the results depicted in the bottom section of Figure 1. The roll-off of D 40 ozone values begins at about mu 3.5 as opposed to mu 2.5 before the adjustment and demonstrates the effectiveness of the corrective procedure.

The correct time to make the c/cw adjustment to lens L1 is after the instrument in question has been initially compared against a reference standard as depicted in the top section of Figure 1. The remedial procedures are not difficult but should be done systematically in order to identify possible changes in the optical transmission of the instrument. Proceed as follows:

Step 1. Perform Hg lamp tests of Q1 S2 (3129 AU) and Q1 S3 (3342 AU). The test results are used later as a reference to determine the degree that L1 was tilted and to determine the relationship of S2 to S3 before any adjustments are made.

Step 2. Perform Standard Lamp tests with one or more lamps since it is desirable to know if the lens adjustment changes the spectral characteristics of the instrument.

Step 3. Adjust the L1 holding bracket in a c/cw rotation so that the top of the bracket is moved about 0.25 mm to the left. **A word of caution. There is a difference between the lens brackets of OLDER and NEWER instruments.**

Older Dobsons. The L1 bracket on older instruments may not have a large guide pin centred on the back of the bracket, therefore, use the **bottom locating pin** as a pivot and file about 0.25 mm from the left edge of the **top locating pin.** It may be necessary to slightly enlarge the clearance holes which accept the two large holding bolts.

Newer Dobsons. The L1 bracket on newer instruments contains a large guide pin centred on the back of the bracket and is used as the rotation pivot. File the top locating pin (as above) and either remove the bottom locating pin or file it by the same amount. Enlarge the clearance holes (as above) if needed.

Step 4. Tighten the L1 bracket in the adjusted position and repeat the Hg lamp tests. It will be found that the Q1 S2 value has decreased by about 2 to 2.5 degrees of Q. This is the desired effect in order to lower the flare spots in the plane of the instrument near S2 and S3.

Step 5. It will be necessary to adjust the bracket of mirror M1 in a c/cw direction in order to re-establish the Q1 S2 value observed at Step 1 (i.e. agreement with the Q1 Table).

Step 6. Repeat the Standard Lamp tests. It will be found that the test values may have changed slightly, usually an increase of about 0.5 R-units on all wavelengths.

There are additional tests which need to be done later but it is first advisable to perform a half-day series of DSGQP observations to determine the effectiveness of the L1 adjustment. Experience with four instruments has shown that a controlled c/cw adjustment of L1 done in small steps of about 0.25 mm will diminish the start of the roll-off effect which was previously evident at about mu 2.5. It is emphasized that it is a trial and error process and there is always the possibility the adjustment may have worsened the roll-off effect by introducing stronger flare spots into the path of slit S2, but to date this has not been experienced.

Step 7. When a satisfactory adjustment has been accomplished the large holding bolts of the L1 bracket should be firmly tightened and a scribe mark placed on the long optical frame around the edge of the bracket. Additional tests should now be made to determine the optical status of the instrument as follows:

(i) Perform AC Test 3 to check the correct focus position of L1.

(ii) Perform several Hg tests of Q1 S2 and Q1 S3 at various temperatures to confirm the S2 to S3 relationship which existed at Step 1 and to confirm the validity of the existing Table of Q1 settings.

(iii) Perform AC Test 12 to determine the correct vertical positioning of the photomultiplier.

After all adjustments and subsequent tests are completed it is desirable to perform a two-lamp optical wedge calibration on wavelengths A, C and D followed by a final inter-comparison against a reference instrument and the establishment of new R-N Tables.

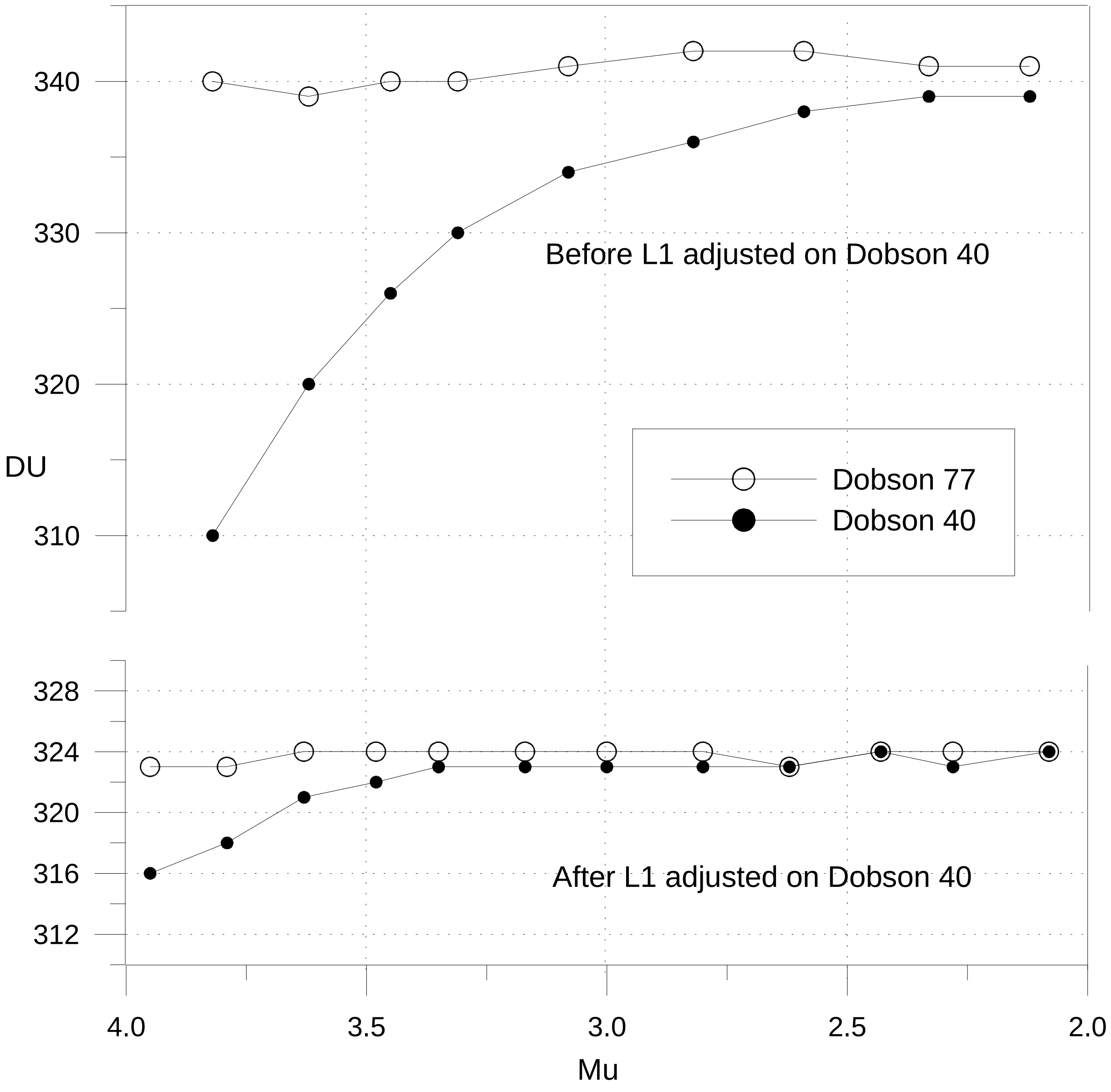

Figure 1. Reduction of ozone roll-off by c/cw adjustment to lens L1

Toronto, Canada
June 1999

Dear Ozone Colleague,

After two and one half years I have completed my memoirs of working with Dobson spectrophotometers over the past forty years. My first encounter with the instrument took place at Resolute in 1959.

I would remind you that this is an **INITIAL DRAFT COPY** which to date has not yet been edited or fully reviewed. I would appreciate any comments you may offer, good, bad or otherwise. From my own viewpoint, some of the more interesting details are to be found in the Appendices which describe some problems not yet previously reported.

Respectfully,

Archie Asbridge