

#606 THE INSTITUTE OF PAPER-CHEMISTRY
(Multi-Step Sector Photometer)
Reports

Institute of Paper Science and Technology
Central Files

PROJECT REPORT FORM

PROJECT NO. 1606 XCOOPERATOR InstituteDATE Dec. 13, 1941 (12/20/1941)NOTE BOOK See Spectrum Plates
NO. CD-1 to CD-4, inclusive

PAGE _____ TO _____

SIGNED J. A. Van den Akker
J. A. Van den Akker

NEW CENCO COREX D ABSORPTION CELLS

Reference is made to recent correspondence with the Central Scientific Company, this project, relative to the construction of absorption cells from Corex D glass. When these cells were received, the writer constructed a small brass box to hold these cells in the sector photometer. This brass box or holder is so designed that the side wall of one cell falls directly in front of the side wall of the other cell, and the two cells, arranged in staggered fashion, comprise a unit optically similar to the double cell constructed not long after the sector photometer was completed.

The Cenco cells appeared to be very nicely constructed, showing practically no optical defects. However, it was desired to test their transmission to ultraviolet light. According to the literature published by the Corning Glass Works, a total thickness of 1 mm. of Corex D glass should transmit light of wavelength somewhat shorter than 250 m μ . (The window thickness of the new Cenco cells is approximately 0.5 mm.) Accordingly, spectrum plates were obtained using either cell alone, filled with distilled water, against air. In another test, an empty cell was tested against air. In a fourth test, the two cells, each filled with distilled water, were tested against each other. All data show that the cells show appreciable absorption characteristics in the ultraviolet with the transmission of the Corex D glass of each cell cutting off rather sharply in the neighborhood of 260 m μ . It may be that the heating necessary to fabricate these cells has somewhat spoiled the ultraviolet transmitting characteristics of the Corex D glass. The Central Scientific Company is being queried on this possibility.

The spectra obtained for wavelengths greater than 260 m μ . appeared very clean and uniform, and in all respects satisfactory for accurate photometric work.

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**THE INSTITUTE OF PAPER CHEMISTRY
APPLETON, WISCONSIN**

33

TO: The Institute of Paper Chemistry

PROGRESS REPORT NO.: 1

FILE NUMBER: 506

DATE: July 1, 1938

SUBJECT

Specifications for the Multi-step Sector Photometer

GENERAL DESCRIPTION

Reference is made to the detailed drawing of June 30, 1938. The apparatus is shown in side elevation in Fig. 1, mounted on the base of the Bausch and Lomb Medium Quartz Spectrograph. The base plate 1 is held in place by the two heavy bolts used to attach various accessories to the spectrograph.

"Front" of the device is that end nearer the slit of the spectrograph. All views shown in the remaining figures are front views, with the exception of Fig. 4 (b), which is a horizontal section.

(4)

X

through solvent plus solute. Spectral transmission data are obtained by inspecting the photographic plate for "match points."

The absorption cells and grating mask are moved in oscillatory fashion. They are mounted on steel reeds and are moved by circular cams carried by the main shaft 3. These two oscillations are in phase and reach peak amplitudes when the centers of the sectors cut across the axis of the collimating system of the spectrograph. Vibratory forces associated with the oscillating absorption cells are rather large and are therefore compensated by a "dummy" oscillating system 17, 18. This latter system has dynamical characteristics similar to the former. Cam 19 drives the dummy system at the same amplitude, but 180° out of phase with the absorption cells. All vibratory forces of translation, and all vibratory torques excepting that about the vertical are compensated. The vibratory torque about the vertical is due mainly to flexural moments and has a negligible effect on the whole system. Member 17 of the dummy system is merely a rectangular frame having mass equal to the sum of mass of the cell holder 11 (Fig. 6) and of the absorption cells 10 and contents. The amplitude of the grating mask 2 is so small (approx. 0.03 inch) that no compensation is required there.

The rotating system is driven by a small motor by way of an endless belt and the pulley 21, which latter also forms the hub of the sector fly wheel 20. The purpose of the fly wheel is to maintain

Light from a concentrated source (not shown on the drawing) passes through one or the other of the two compartments of the double absorption cell 10, dimensions of which are given in an attached photostat. If the light passes through the compartment containing clear solvent, the sector wheel 6 is in such position that the beam passes through the sector having a number of zones of different angular openings, and thence passes on to the grating mask 2 which casts a series of shadows on the slit; as viewed from the slit, the light falls on the right half of the grating mask, so that eleven illuminated bands separated by ten dark bands cover the slit. These are imaged on the photographic plate. The zones of the variable sector center upon the openings of the right half of the grating mask. In the case of the sector wheel illustrated in Fig. 3 (it is interchangeable with wheels having logarithmic openings), the angles of the zones are 100° , 90° , 80° , 70° , 60° , 50° , 40° , 30° , 20° , 10° and 5° . Thus, relative to the amount of light passed by a zone of 100° , the energies falling in the illuminated zones are 100, 90, 80,, 10 and 5 per cent. During the next half revolution of the sector wheel the light passes through the test solution, the 100° -degree aperture, and the left half of the grating mask. Those portions of the slit previously shadowed are now illuminated, and vice-versa, those portions previously illuminated are now shadowed. Thus a series of spectra are formed, alternate bands being due to light passing through clear solvent, with the intervening bands due to light passing

constant speed during one complete revolution (see appendix).

The cam 7, which drives the grating mask, is integral with the sector wheel 6. The sector wheel is accurately centered, and the cam is off center by 0.020 inch, but the combination of sector wheel and cam is statically balanced. The cams 15 and 19 together are statically balanced, and the fly wheel is completely balanced. Static balance is best obtained by the Kirkpatrick method (The Review of Scientific Instruments, 9, No. 4:140 (April, 1938)).

Amplitudes of oscillation are governed by the width of the beam accepted by the spectrograph and the width of zone between the two halves of the respective oscillators. The half width of the beam at the grating mask is of the order of $0.0035''$ or less, that of the zone of overlap of the rods comprising the grating is of similar order, so that an amplitude of $0.03''$ should be more than adequate ($0.03 \cos 50^\circ = 0.02''$ is approximate displacement when the edge of the 100° sector cuts the axis). The half width of the beam at the double absorption cell is about $0.02''$, that of the central zone of the cell is about $0.04''$, so that an amplitude of $0.12''$ should be more than adequate ($0.12 \cos 50^\circ = 0.077''$).

The three oscillating systems are designed to have natural frequencies of vibration near that of the driving system (30 r.p.s.). The mathematical treatment is given in the appendix.

SPECIFICATIONS AND CONSTRUCTION NOTES

In the following, numbers refer to the numbered parts of the attached drawing.

1. Steel or iron plate, top and bottom surfaces planed flat and smooth.
2. Brass frame and retaining strips. Rods of #68 drill rod, 0.031" diameter. Must be smooth, free of scratches, and diameter must be uniform, especially near the central ends. Forty-two rods are required: 21 must be 0.4000 ± 0.0003 inches long, and 21 must be 0.1 ± 0.01 inches long. The retaining strips must have inner edges straight to within ± 0.0002 inches (they might be finished by grinding on plate glass). The ends of all rods must be free of burrs and the central ends of the longer rods must finish squarely (by grinding). Soldering is done only after the whole assembly (including retainer strips) is properly clamped together. The central zone of overlap must be straight and of uniform width of about 0.01". In laying the rods, care should be exercised in seeing that the length of pile of 21 long and short rods is about the same on the two sides. A nick, burr or scratch on a rod near the central portion might affect the accuracy of the method.
3. Starrett flat stock. Bent so that pivots 4 hold grating mask tightly, and so bent that they are straight and parallel when installed. Should be tempered. Adjusted in base clamps 5 so that total

clearance between 3 and 7 is of order of 0.001" and rods move parallel to themselves.

4. Hardened drill rod. Tight tapered fit and silver soldered (Fig. 4(b)). Pair on left to fit pivot holes (small) shown in Fig. 4(a).

5. Steel. Bottom faces and clamping surfaces ground flat.

6. Brass sheet. Laying out should be done with very sharp pointed dividers and scriber, and a reliable steel straight edge. The surface should be polished before the figure is constructed. The center point should be as light as possible. The angles should be laid out on a large circle, of diameter about 8 inches; i.e., the work should start with a metal sheet approximately 9 inches square. The total angles of the two sectors need not be precisely 100° , but they should be precisely equal. Division of the upper sector in Fig. 3 should be carried out very carefully with dividers, by the process of bisection, if a large, accurate protractor is not available. As stated earlier in this report the angular openings of the zones are 100° , 90° , 50° , . . . 20° , 10° and 5° . The error in scribing the zone limits should be kept to within 0.1° (0.1 per cent at 100 per cent transmission, 2 per cent at 5 per cent transmission). The radial edges of the zones should be beveled on the rear face; after beveling, the edges should not be actually sharp, for they would be too fragile - an edge thickness of about 0.01" is recommended. If fine scribing lines are used, filing to the lines should result in a precise piece of work. The central hole should be drilled and cut accurately on center after the scribing is completed. The size

of the hole will be slightly less than $0.473''$, to fit the main shaft snugly (but not so snugly as to make removal difficult). The sector wheel is then bolted to 7, and the combination is statically balanced by adding sectors of solder to the back surface of the sector wheel (adjacent to the limits of the 100° sector).

7. Steel. Central hole to fit snugly on shaft (diameter slightly less than $0.473''$), and off center by $0.02''$. Mark with arrow as shown in Fig. 3, making sure that arrow is on line with the two centers. Outer surface ground to nearly polished finish. The contacting surfaces of 3 should likewise be very smooth. Edge of set-screw hole slightly rounded.

8. Drill rod, carefully selected for straightness.

9. New Departure, bearing no. 1201.

10. Double absorption cell; see second attached photostat.

11. Brass box, to fit 10 snugly. Holes 13 to fit 12 friction tight; 12 should be driven in place. Soldered while clamped together.

12. Steel drill rod, $1/16''$ diameter. To fit 13 with friction tightness and 14 snugly but not tightly.

13. No further comment.

14. Starrett flat stock. Not pre-bent like 3. Bearing blocks at upper ends silver soldered to reeds. Tempered. Clearance between 14 and 16 negligible.

15. Steel. Comments similar to 7 except hole size to fit $1/2''$ shaft snugly, and off center by $0.080''$.

16. Starrett flat stock or other steel stock $1/16$ " thick silver soldered to 14. Smooth faces centered on axis of shaft.

17. Rectangular brass frame, to weigh about 41 grams. Must not interfere with light beam. Merely to compensate for forces on 10, 11 and contents.

18. Similar to 14, except for slight difference of mounting of 17. Blocks similar to 16 silver soldered, as on 14.

19. Exactly similar to 15, but mounted 180° from 15. Check static balance of 15 and 19 taken together, make corrections by borings from side, if necessary.

20. Brass. Bolted and soldered to 21.

21. Brass. 20 and 21, mounted on shaft together, must be carefully balanced. Sectors must center on sectors of 6 to within 0.5° .

22. Brass. Appropriate width to hold 9 satisfactorily. Bearing retaining ring filed flat on top to avoid possible interception of light beam, as shown.

23. Brass, $1/32$ " thick. Inner edges exceedingly straight. Not soldered until reeds in place.

APPENDIX

CALCULATION OF DIMENSIONS OF STEEL REEDS

According to Kimball (Vibration Prevention in Engineering), the frequency of the first mode of vibration of a reed clamped at one end

is obtained from

$$\left(\frac{w\omega^2}{gEI}\right)^{1/4} L = 1.875$$

where

w = weight per unit length

or w/g = mass, "m", per unit length

L = length

ω = $2\pi f$

E = Young's modulus

I = moment of inertia of section of reed

If M_0 is the equivalent mass placed at the end of a weightless reed of similar elastic characteristics,

$$\omega = \sqrt{\frac{k}{M_0}}$$

$$\text{also } \omega = \left(\frac{1.875}{L}\right)^2 \sqrt{\frac{EI}{m}}$$

It is well known that

$$k = F/y = 3EI/L^3;$$

substituting,

$$M_0 = 0.243 m L$$

It is now assumed that when an additional mass, M , is placed at the end of the reed, the frequency is given by

$$f = \frac{1}{2H} \sqrt{\frac{3EI/L^3}{0.243 = L \rightarrow H}}$$

For the system 2, 3 (see drawing), the following numerical values were used:

$f = 35/\text{sec.}$, $E = 2.0 \times 10^{12} \text{ d/cm.}^2$,
 $L = 11 \text{ cm.}$, $*W = 7.25 \text{ gm.}$,
width of reed, 0.8 cm.

*21 long steel rods	0.51 gm.
21 short steel rods	0.21
brass frame and strips	<u>13.50</u>
	14.5 gm.

One half this mass is used, because there are two reeds. The density of steel was assumed to be 7.80, that of brass, 8.50. Solving, it is found that 3/64" steel flat stock would be suitable.

For the system 14, 11, 10 (and contents), similar data were used, except that the width of the reeds was taken to be 1.40 cm., and $H = 20.2 \text{ gm.}^*$

*brass frame	26.2 gm.
quartz cell	10.0
water	<u>4.2</u>
	40.4 gm.

Solving, it is found that the thickness of reeds should be 0.139 cm. Flat stock $3/64"$ is conveniently used, this thickness giving a frequency of 30.6/sec. Hence a driving frequency of 30/sec. would be suitable; adjustable small masses on the reeds of the lighter system 2, 3 will permit adjustment of the frequency of this system down to resonance with the two heavier systems.

VARIATION IN SPEED OF SHAFT WHEN SPEED IS OFF RESONANCE WITH REED SYSTEMS

For proper time division by the sector wheel 6, the rotational speed must be quite constant. At resonance, the variations would be nil. The driving force, for negligible damping, is given by

$$F = A (K - m\omega^2) \cos \omega t$$

(where notation is that of "Lecture Notes," vol. 1). There are four of the heavier reeds. The torques are additive, hence we may write

$$F = 4 A m \left(\frac{K}{m} - \omega^2 \right) \cos \omega t$$

Now $K/m = 4 \pi^2 r^2 = 37,400/\text{sec.}^2$ and $m = 20.2 + 0.243 \times 14.3 = 23.7 \text{ gm.}$

Let $A = 0.5 \text{ cm.}$, and suppose that the shaft runs at half speed, so that $\omega^2 = 9400$. Then the torque is seen to be

$$L = 660,000 \sin \omega t \cos \omega t .$$

The change in angular momentum over a quarter revolution is

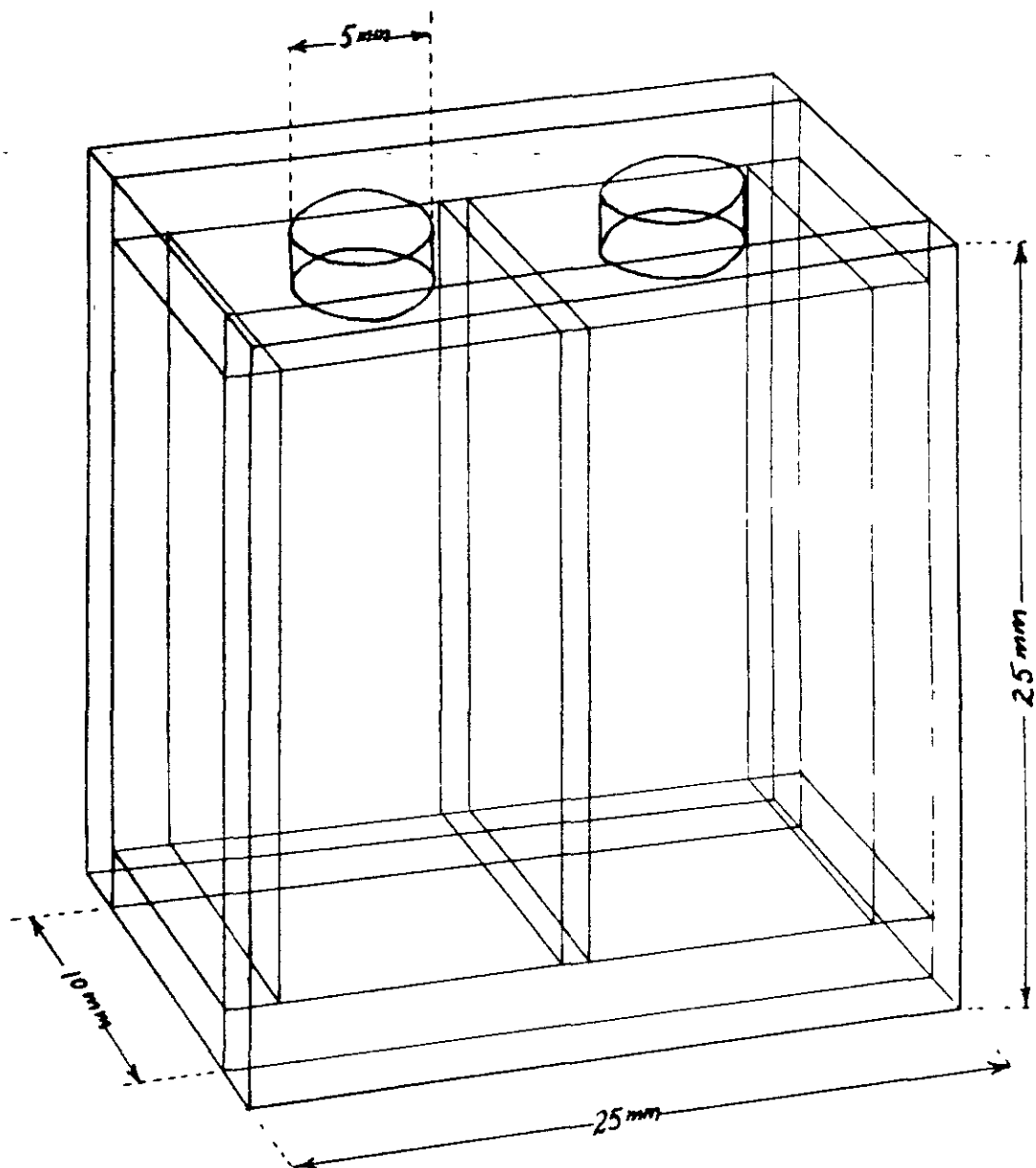
$$I \delta \omega = \frac{660,000}{\omega} \int_{\omega t = 0}^{\omega t = \pi/2} \sin \omega t \cos \omega t d(\omega t) .$$

This leads to the result, $\delta \omega / \omega = 33 / I$. If, for this speed (half of resonant), we wish to have $\delta \omega / \omega < 0.01$, then I must be greater than 3300. For a sector fly wheel having two 120° openings, $I = (1/6) MR^2$. If $R^2 = 50 \text{ cm.}^2$, $M = 400 \text{ gm.}$, the thickness of a brass fly wheel should be greater than $0.114''$. Actually, a thickness of about $0.19''$ is used, so that the maximum variation in speed at half resonant speed should be about 0.6 per cent. Near resonance, then, the speed variations should be entirely negligible.

THE INSTITUTE OF PAPER CHEMISTRY

J. A. Van den Akker
 J. A. Van den Akker,
 Research Associate

Westbrook Steele
 Westbrook Steele, for the Technical
 Director



Fused quartz double absorption cell

Thickness of liquid: 1.00 cm.

Wall thickness: 2 mm.

Partition thickness: 1 mm.

4:1

J. A. Van den Akker
6/23/38

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PROJECT REPORT FORM

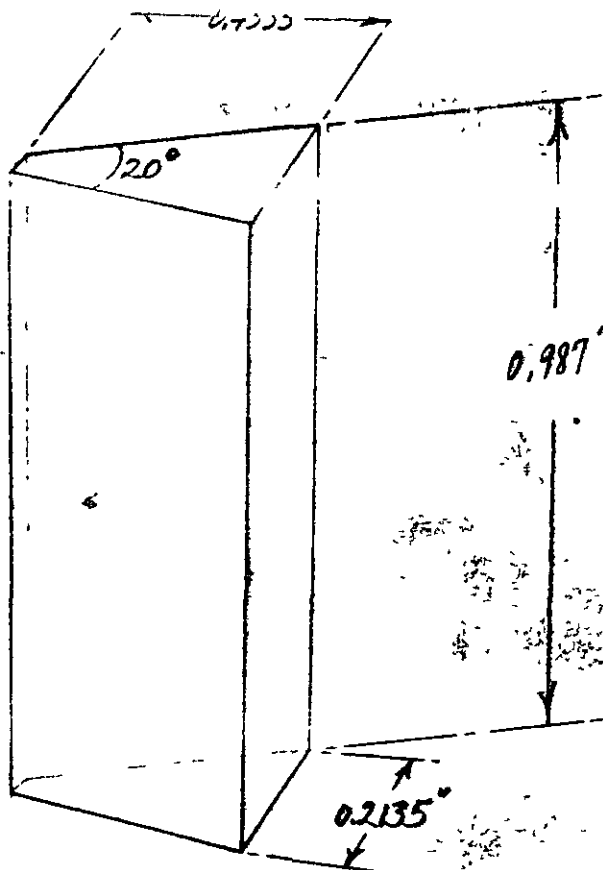
PROJECT NO. 606 X
 COOPERATOR Basile
 DATE January 10, 1941
 NOTE BOOK None
 PAGE _____ TO _____
 SIGNED J. A. Van den Acker
 J. A. Van den Acker

**FUSED QUARTZ DEVIATION PRISMS FOR QUANTITATIVE SPECTRUM ANALYSIS
 AND COMPARISON OF SPECTRAL ENERGY DISTRIBUTION OF LAMPS**

In the patent specification for the multi-step sector photometer and in the descriptive matter contained in File 606, a possible use of the multi-step sector photometer relating to the comparison of spectral energy distribution of light sources is described. The light sources to be compared are placed side by side, with the optical axis of the spectrograph and the photometer bisecting the line connecting the centers of the sources. By means of two quartz deviation prisms placed in a holder which, in turn, is placed in the absorption cell holder of the photometer, the virtual images of the two sources are alternately placed on the axis of the spectrograph.

It has occurred to the writer that quantitative spectrum analysis may be performed by making the light sources to be compared respectively a pair of spectroscopic carbons containing known amounts of materials under investigation, and a pair of exactly similar spectroscopic carbons containing the unknown amounts of materials investigated; if the two arcs are operated electrically in series, and are set at the same gap, the relative intensities of the spectrum lines in the spectra of the "known" and "unknown" arcs can be obtained in the usual manner.

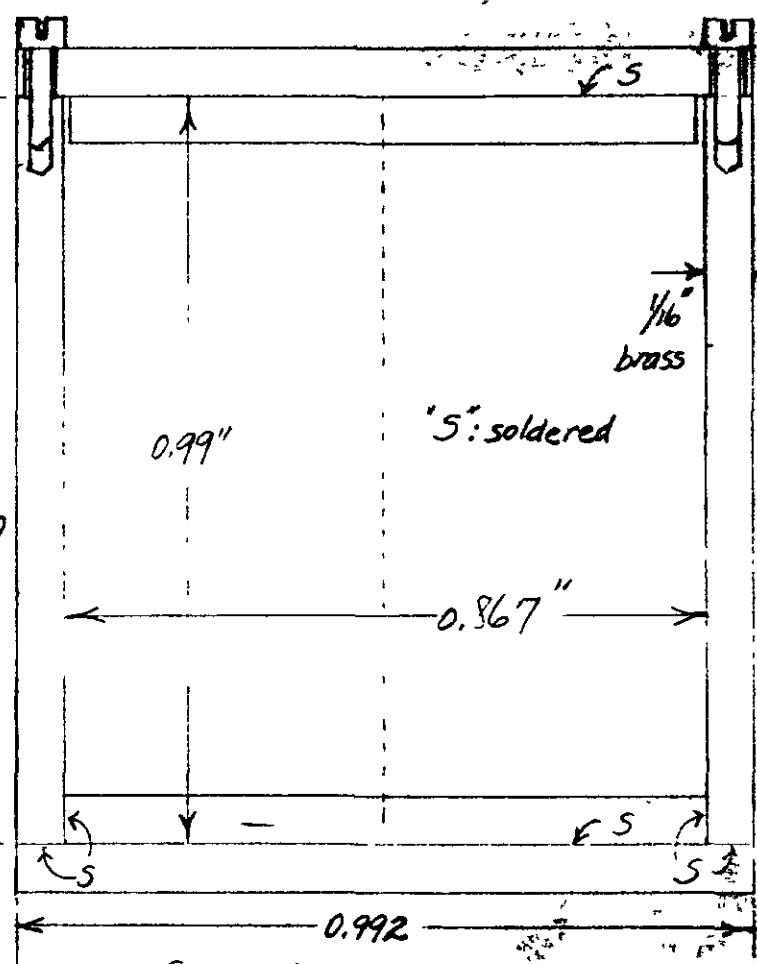
The above possibility seems so promising that deviating prisms of fused quartz were designed, and the design submitted to various possible



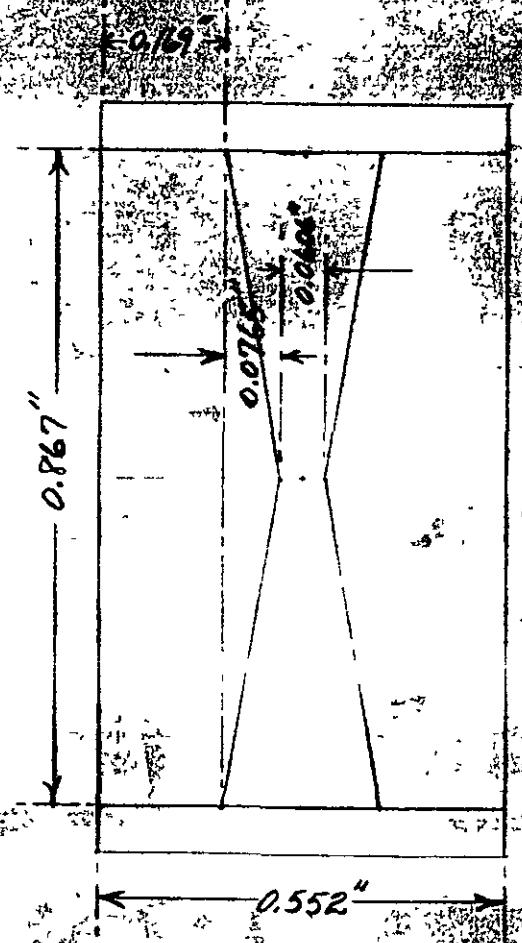
not →
to
scale

Holder for fused
quartz prisms.
See project report

1/9/41
Java



Side elevation 10 cm. = 1 inch



Bottom of holder
(For note similar to supporting structure)

PROJECT REPORT FORM

PROJECT NO. 606
COOPERATOR Institute
REPORT NO. 1
DATE March 1, 1939
NOTE BOOK 124
PAGE 37142 TO 37152
SIGNED C.H. Root

G. H. Root

A Multi-step Sector Photometer attachment for the Bausch & Lomb Medium Quartz Spectrograph was constructed according to plans drawn by Dr. Van den Akker.

After lining up and mounting on the spectrograph, tests were conducted to determine its accuracy and suitability for transmission and reflectance measurements in the ultraviolet. As a preliminary step to obtaining actual measurements on the instrument the wavelength scale was accurately calibrated against known values of copper and mercury lines. A correction chart was made for use in subsequent tests.

While construction of a fused quartz transmission cell was under way, a technique was developed for obtaining reflectance measurements. A semi-circular cardboard sheet smoked with magnesium oxide was cemented to the sector fly wheel of the Photometer in such a way that it completely covered the "standard" or 100 per cent opening of the fly wheel. A sheet of the paper whose reflectance was to be measured was cemented to the other half of the sector fly wheel such that it completely covered the "sample" opening. Light from an ultraviolet source (such as a mercury vapor lamp, or an iron arc) was focused by means of a quartz lens on the plane of the sample and standard, at a point on the optical axis. The light was placed such that the angle of incidence was about 45 degrees. For samples of low reflectance in the ultraviolet, it was found necessary to have a neutral standard of low reflectance. This was obtained by mounting a rotating neutral screen sector in the incident light beam such that when the magnesium oxide standard was in position the screen would also be in the incident beam. When the standard had rotated out of position and the sample was coming into position, the screen would also have rotated out of position so that there was no filter in the beam. This rotating screen was driven and kept in synchronization by means of a flexible shaft attached to the rotating member of the Photometer. The screen chosen gave a transmission of 25 per cent so when it was in use, measurements could be obtained at 2.5 per cent intervals up to 25 per cent. Photographic plates were exposed for several paper samples, and the reflectance values in the visible portion were compared to the reflectances obtained on the G.E.R.S. In every case very good agreement was obtained. It was found possible in most cases to obtain data for curves down to 230 millimicrons.

After completion of the divided quartz transmission cell, measurements were obtained as follows:

1. Uniformity of cell

The cell was carefully cleaned and both sections filled with distilled water. An exposure was taken to determine any flaws or irregularities in the quartz faces. The plate showed that both

sections used were of good uniformity and gave matched fields.

2. Correction factor for cell thickness

To compare transmission data in the visible region of the spectrum with data obtained on the G.E.R.S., it was necessary to know the correction factor to be applied because of the different cell thickness used on the G.E.R.S. Careful measurements were obtained of the thickness of solution of the different cells used. The quartz transmission cell was found to have an average liquid thickness of 10.30 mm., while the glass transmission cells used on the G.E.R.S. were found to have an average liquid thickness of 5.24 mm. This gave a correction factor of 1.965 which means that to compare transmissions on the G.E.R.S. against the quartz spectrograph, the G.E.R.S. values must be raised to the 1.965 power, e.g., a transmission of 60 per cent on the G.E.R.S. would show a transmission on the spectrograph of $60^{1.965}$ or 37 per cent.

3. Transmission measurements of methyl violet solution

Transmission measurements were obtained on the G.E.R.S. and on the quartz spectrograph of a methyl violet solution. The correction factor was applied and the curves in the visible portion of the spectrum were plotted. The maximum error (on the steep portion of the curve) was found to be 3.9 per cent, while the average error was 0.46 per cent.

Solutions measured in connection with other projects were compared with the G.E.R.S. curves with equally good agreement.

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SIGNED _____
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 TITLE _____
 DATE _____
 REPORT NO _____
 COOPERATION _____

PROJECT REPORT FORM

**THE INSTITUTE OF PAPER CHEMISTRY
APPLETON, WISCONSIN**

93.

TO: The Institute of Paper Chemistry

PROGRESS REPORT NO.: 1

FILE NUMBER: 606

DATE: July 1, 1938

SUBJECT

Specifications for the Multi-step Sector Photometer

GENERAL DESCRIPTION

Reference is made to the detailed drawing of June 30, 1938. The apparatus is shown in side elevation in Fig. 1, mounted on the base of the Bausch and Lomb Medium Quartz Spectrograph. The base plate 1 is held in place by the two heavy bolts used to attach various accessories to the spectrograph.

"Front" of the device is that end nearer the slit of the spectrograph. All views shown in the remaining figures are front views, with the exception of Fig. 4 (b), which is a horizontal section.

(4)

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Light from a concentrated source (not shown on the drawing) passes through one or the other of the two compartments of the double absorption cell 10, dimensions of which are given in an attached photostat. If the light passes through the compartment containing clear solvent, the sector wheel 6 is in such position that the beam passes through the sector having a number of zones of different angular openings, and thence passes on to the grating mask 2 which casts a series of shadows on the slit; as viewed from the slit, the light falls on the right half of the grating mask, so that eleven illuminated bands separated by ten dark bands cover the slit. These are imaged on the photographic plate. The zones of the variable sector center upon the openings of the right half of the grating mask. In the case of the sector wheel illustrated in Fig. 3 (it is interchangeable with wheels having logarithmic openings), the angles of the zones are 100° , 90° , 80° , 70° , 60° , 50° , 40° , 30° , 20° , 10° and 5° . Thus, relative to the amount of light passed by a zone of 100° , the energies falling in the illuminated zones are 100, 90, 80,, 10 and 5 per cent. During the next half revolution of the sector wheel the light passes through the test solution, the 100° -degree aperture, and the left half of the grating mask. Those portions of the slit previously shadowed are now illuminated, and vice-versa, those portions previously illuminated are now shadowed. Thus a series of spectra are formed, alternate bands being due to light passing through clear solvent, with the intervening bands due to light passing

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6. Brass sheet. Laying out should be done with very sharp pointed dividers and scriber, and a reliable steel straight edge. The surface should be polished before the figure is constructed. The center point should be as light as possible. The angles should be laid out on a large circle, of diameter about 8 inches; i.e., the work should start with a metal sheet approximately 9 inches square. The total angles of the two sectors need not be precisely 100° , but they should be precisely equal. Division of the upper sector in Fig. 3 should be carried out very carefully with dividers, by the process of bisection, if a large, accurate protractor is not available. As stated earlier in this report the angular openings of the zones are 100° , 90° , 80° , . . . 20° , 10° and 5° . The error in scribing the zone limits should be kept to within 0.1° (0.1 per cent at 100 per cent transmission, 2 per cent at 5 per cent transmission). The radial edges of the zones should be beveled on the rear face; after beveling, the edges should not be actually sharp, for they would be too fragile - an edge thickness of about 0.01" is recommended. If fine scribing lines are used, filing to the lines should result in a precise piece of work. The central hole should be drilled and cut accurately on center after the scribing is completed. The size

of the hole will be slightly less than 0.473", to fit the main shaft snugly (but not so snugly as to make removal difficult). The sector wheel is then bolted to 7, and the combination is statically balanced by adding sectors of solder to the back surface of the sector wheel (adjacent to the limits of the 100° sector).

7. Steel. Central hole to fit snugly on shaft (diameter slightly less than 0.473"), and off center by 0.02". Mark with arrow as shown in Fig. 3, making sure that arrow is on line with the two centers. Outer surface ground to nearly polished finish. The contacting surfaces of 3 should likewise be very smooth. Edge of set-screw hole slightly rounded.

8. Drill rod, carefully selected for straightness.
9. New Departure, bearing no. 1201.
10. Double absorption cell; see second attached photostat.
11. Brass box, to fit 10 snugly. Holes 13 to fit 12 friction tight; 12 should be driven in place. Soldered while clamped together.
12. Steel drill rod, 1/16" diameter. To fit 13 with friction tightness and 14 snugly but not tightly.
13. No further comment.
14. Starrett flat stock. Not pre-bent like 3. Bearing blocks at upper ends silver soldered to reeds. Tempered. Clearance between 14 and 16 negligible.
15. Steel. Comments similar to 7 except hole size to fit 1/2" shaft snugly, and off center by 0.050".

16. Starrett flat stock or other steel stock $1/16''$ thick silver soldered to 14. Smooth faces centered on axis of shaft.

17. Rectangular brass frame, to weigh about 41 grams. Must not interfere with light beam. Merely to compensate for forces on 10, 11 and contents.

18. Similar to 14, except for slight difference of mounting of 17. Blocks similar to 16 silver soldered, as on 14.

19. Exactly similar to 15, but mounted 180° from 15. Check static balance of 15 and 19 taken together, make corrections by borings from side, if necessary.

20. Brass. Bolted and soldered to 21.

21. Brass. 20 and 21, mounted on shaft together, must be carefully balanced. Sectors must center on sectors of 6 to within 0.5° .

22. Brass. Appropriate width to hold 9 satisfactorily. Bearing retaining ring filed flat on top to avoid possible interception of light beam, as shown.

23. Brass, $1/32''$ thick. Inner edges exceedingly straight. Not soldered until rods in place.

APPENDIX

CALCULATION OF DIMENSIONS OF STEEL REEDS

According to Kimball (Vibration Prevention in Engineering), the frequency of the first mode of vibration of a reed clamped at one end

is obtained from

$$\left(\frac{w\omega^2}{gEI}\right)^{1/4} L = 1.875$$

where

w = weight per unit length

or w/g = mass, "m", per unit length

L = length

$\omega = 2\pi f$

E = Young's modulus

I = moment of inertia of section of reed

If M_0 is the equivalent mass placed at the end of a weightless reed of similar elastic characteristics,

$$\omega = \sqrt{\frac{k}{M_0}}$$

also
$$\omega = \left(\frac{1.875}{L}\right)^2 \sqrt{\frac{EI}{m}}$$

It is well known that

$$k = F/y = 3EI/L^3;$$

substituting,

$$M_0 = 0.243 m L$$

It is now assumed that when an additional mass, M , is placed at the end of the reed, the frequency is given by

$$f = \frac{1}{2W} \sqrt{\frac{3EI/L^3}{0.243mL + M}}$$

For the system 2, 3 (see drawing), the following numerical values were used:

$$f = 35/\text{sec.}, \quad E = 2.0 \times 10^{12} \text{ d/cm.}^2,$$

$$L = 11 \text{ cm.}, \quad *M = 7.25 \text{ gm.},$$

width of reed, 0.8 cm.

*21 long steel rods	0.81 gm.
21 short steel rods	0.21
brass frame and strips	<u>13.50</u>
	14.5 gm.

One half this mass is used, because there are two reeds. The density of steel was assumed to be 7.80, that of brass, 8.80. Solving, it is found that 3/64" steel flat stock would be suitable.

For the system 14, 11, 10 (and contents), similar data were used, except that the width of the reeds was taken to be 1.40 cm., and $M = 20.2 \text{ gm.}^*$

*brass frame	26.2 gm.
quartz cell	10.0
water	<u>4.2</u>
	40.4 gm.

Solving, it is found that the thickness of reeds should be 0.130 cm. Flat stock 3/64" is conveniently used, this thickness giving a frequency of 30.5/sec. Hence a driving frequency of 30/sec. would be suitable; adjustable small masses on the reeds of the lighter system 2, 3 will permit adjustment of the frequency of this system down to resonance with the two heavier systems.

VARIATION IN SPEED OF SHAFT WHEN SPEED IS OFF RESONANCE WITH REED SYSTEMS

For proper time division by the sector wheel 6, the rotational speed must be quite constant. At resonance, the variations would be nil. The driving force, for negligible damping, is given by

$$F = A (K - m\omega^2) \cos \omega t$$

(where notation is that of "Lecture Notes," vol. 1). There are four of the heavier reeds. The torques are additive, hence we may write

$$F = 4 A m \left(\frac{K}{m} - \omega^2 \right) \cos \omega t$$

Now $K/m = 4 \pi^2 f^2 = 37,400/\text{sec.}^2$ and $m = 20.2 + 0.243 \times 14.3 = 23.7 \text{ gm.}$

Let $A = 0.5 \text{ cm.}$, and suppose that the shaft runs at half speed, so that $\omega^2 = 9400$. Then the torque is seen to be

$$L = 660,000 \sin \omega t \cos \omega t .$$

The change in angular momentum over a quarter revolution is

$$I \delta\omega = \frac{660,000}{\omega} \int_{\omega t = 0}^{\omega t = \pi/2} \sin \omega t \cos \omega t d(\omega t).$$

This leads to the result, $\delta\omega/\omega = 33/I$. If, for this speed (half of resonant), we wish to have $\delta\omega/\omega < 0.01$, then I must be greater than 3300. For a sector fly wheel having two 120° openings, $I = (1/6) MR^2$. If $R^2 = 50 \text{ cm.}^2$, $M = 400 \text{ gm.}$, the thickness of a brass fly wheel should be greater than $0.114''$. Actually, a thickness of about $0.19''$ is used, so that the maximum variation in speed at half resonant speed should be about 0.6 per cent. Near resonance, then, the speed variations should be entirely negligible.

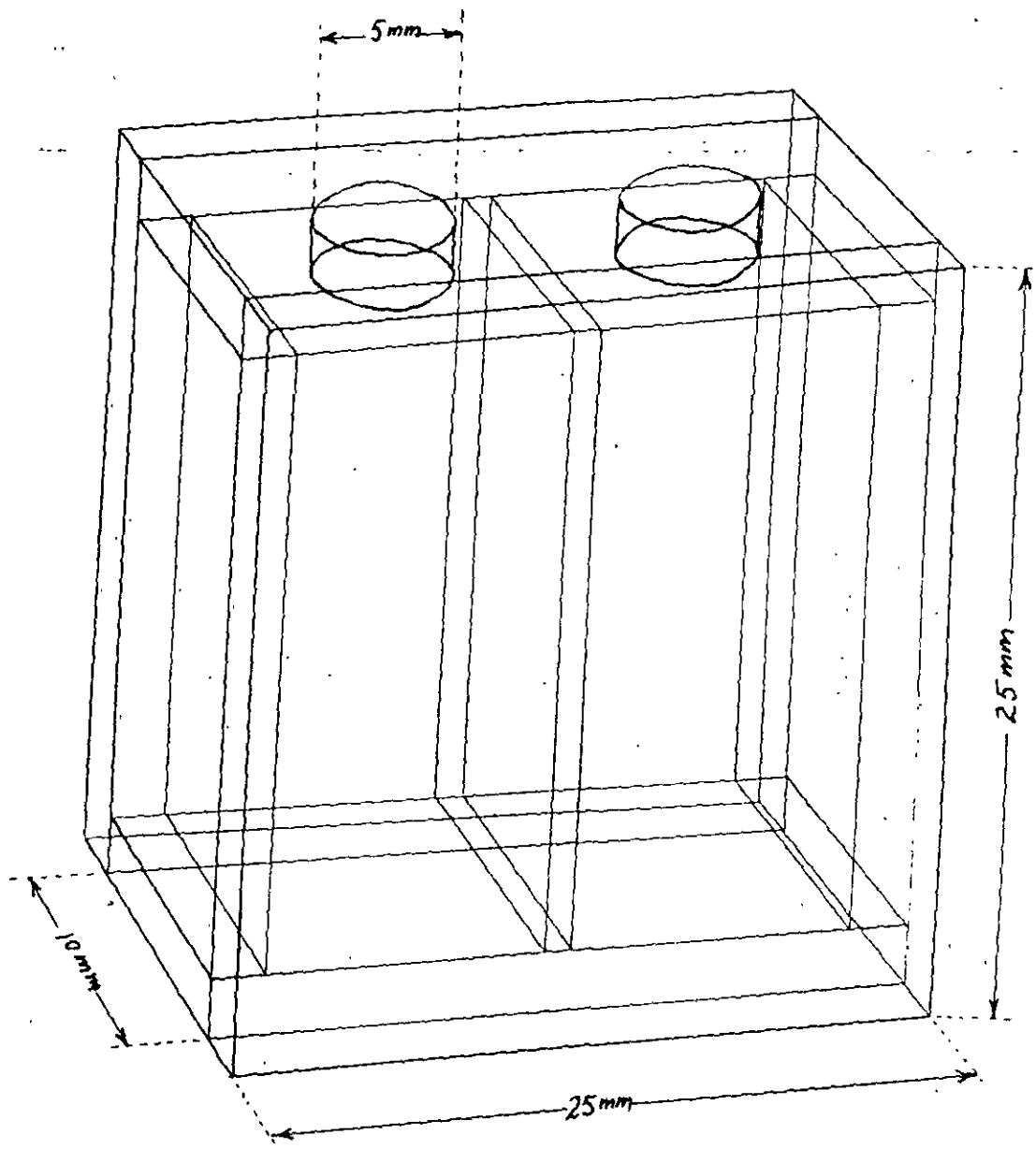
THE INSTITUTE OF PAPER CHEMISTRY

J. A. Van den Akker

 J. A. Van den Akker,
 Research Associate

Westbrock Steele

 Westbrock Steele, for the Technical
 Director



Fused quartz double absorption cell

Thickness of liquid: 1.00 cm.

Wall thickness: 2 mm.

Partition thickness: 1 mm.

4:1

J.A. Van den Akker
6/23/38

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J. A. Van den Akker

MAILED JUL 5 - 1938

During the two weeks ending June 30th, the multi-step sector photometer was designed. The detailed drawings were finished and signed on June 30, 1938.

The final design incorporates a few significant improvements over the original conception of the physical embodiment of the basic idea. These improvements are:

1. The complete absence of lenses or other optical parts (excepting the absorption cell itself).
2. The use of rapidly oscillating absorption cells instead of rotating cells. This change results in the following improvements:
 - (a) The volume of solution required has been reduced by a factor of about ten, the actual volume now required being 2.1 cc. or less. This will enable determinations where the available quantity of solution is small.
 - (b) The reduction in size of cell should decrease the cost of the cell.
 - (c) The use of oscillating cells eliminates the necessity of a separate shaft (flexibly mounted) to carry the rotating cells, thereby simplifying and reducing the size of the instrument. The dimensions of the base plate of the instrument are 6" x 6".

In addition to these, a few minor mechanical improvements have been made. For example, the absorption cells are mounted on steel reeds, moved by circular cams, and a vibrating system having similar dynamical characteristics is mounted alongside, vibrating out of phase by 180° , to compensate vibrations due to the former system. Both systems are designed to have natural frequencies closely resonant with the driving frequency (see appendix of progress report No. 1). A sector fly wheel with a pulley on the hub will maintain constant speed during one revolution.

The elimination of optical parts will remove difficulties due to dispersion, and it should be possible to obtain in one spectrogram all data for the wavelength range of the spectrograph. It might seem necessary, in the present design, to have the grating mask immediately adjacent to the plane of the slit, and to employ a "point source." An analysis shows, however, that the arrangement should be satisfactory when the grating mask is over one-half inch distance from the slit and a source of about one-quarter inch diameter and two or three feet distance is used. Due to the formation of a penumbra, the region between adjacent banded spectra will not be quite as fine as that obtained with a carefully corrected optical system. However, the energy arriving at the banded spectra at match points is constant from the test spectrum to the comparison spectrum, i.e., a discernible band between adjacent spectra should not be present at match points. This is concluded from a study of the distribution of total energy over superimposed penumbras. Diffraction effects, while small, would

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PROJECT NO. 606
CLIENT _____
REPORT NO. _____
DATE June 16 to June 30, 1938
NOTE BOOK _____
PAGE _____ TO _____
SIGNED _____

page 2

likewise cause no discernible effects at match points.

Specifications are given in progress report No. 1.

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