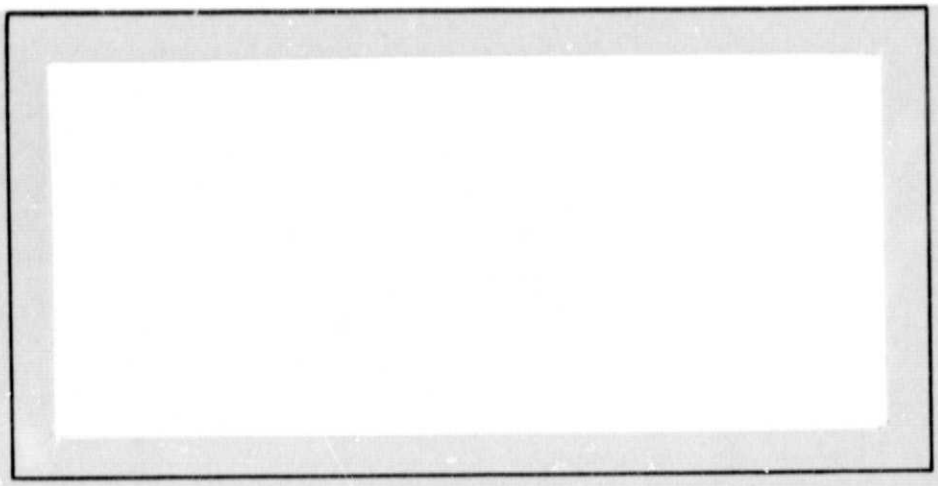

SCIENCE APPLICATIONS INCORPORATED

SAI-79-762-HU

FINAL REPORT
FOR
ADVANCED DESIGNS
FOR FLUID FLOW VISUALIZATION

Prepared for:

National Aeronautics and Space Administration
Space Sciences Laboratory
Aerospace Environments Division
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Contract: NAS8-31173

October 1978

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1. Introduction

The overall aim of this program was to provide continuing research on existing and new designs for minimally intrusive measurement of flow fields and temperature fields in the Geophysical Fluid Flow Cell (GFFC) and the proposed Atmospheric General Circulation Experiment (AGCE). The program was a continuation of a study by SAI that included the development of a preliminary design of an optical system for the GFFC apparatus. The schedule has allowed SAI to work in close contact with the NASA scientists involved with the GFFC and the AGCE and SAI has remained flexible to the evolving needs of the NASA requirements.

The statement of work for this study has been an organic document; activity evolving in direct response to developments by NASA that required special attention. Nevertheless, all the major elements in the original statement of work received attention, either directly by SAI or by other NASA contractors. The original statement of work was divided into four major areas as follows: (Details are presented in Table 1.)

- Identification and removal of foreign particles from photochromic solutions
- Search for higher dielectric photochromic solutions
- Selection of UV light source
- Analysis of refractive techniques

TABLE 1. SUMMARY OF WORK STATEMENT

- Identification and Removal of Foreign Particles
  - Analysis of Particles
  - Preparation of Particle-Free Fluids
- Search for Higher Dielectric Photochromic Solutions
  - Search for New Photochromic Compounds
  - Selection of High Dielectric Fluids
  - Testing of New Photochromic Solutions
- Selection of UV Light Source
  - Survey of Available Sources
  - Selection of Source
- Analysis of Refractive Techniques
  - Refinement of Moire' Techniques
  - Examination of Alternates

Added Task

- Examination of Fresnel Lens Applicability

2. Identification and Removal of Foreign Particles

NASA observed that minute particles of an unknown origin were present in the photochromic solutions which disrupted the flow under high electric fields. They exhibited a "cobweb effect", lining up with respect to the electric field and breaking down disruptively. The particles would first align with the field, then move in a tornado-like fashion, upsetting the flow and the imposed photochromic patterns in the immediate vicinity. Such activity would be experimentally disastrous if it occurred during attempts to take data.

The source of these particles was assumed to be one or more of four potential sources. These include dust particles or insoluble contaminants within the Dow-Corning Silicone Fluid, dust particles or insoluble impurities within the undissolved photochromic dye, particles introduced during the filling of the experimental containers, or possibly precipitated photochomic material produced by either excessive UV irradiation or prolonged exposure to high electric fields. Dust particles introduced as a result of the first three potential sources can be erradicated by ultra filtration techniques undertaken in an adequate clean room. Once this is accomplished, precipitated photochromic material can be prevented by using greater care in exposing the photochromic solution for extended periods to excessive UV radiation or high electric fields. Excessive exposure to either will cause the photochromic to undergo an additional, irreversible, chemical change to form an insoluble precipitate. Since this precipitate normally adheres to the glass surface through which the excessive UV irradiation enter the solution, it is not known whether it could actually be a cause of the disruptive "cobweb effect".

Shortly after the study had begun, NASA indicated that the problem of removing foreign particles from the photochomic solutions had been taken care of and that an adequate clean room facility had been located within NASA's local research laboratory. SAI had initially helped NASA with this problem by recommending and acquiring various types of filters to be used during the clean room preparation of the solutions.

3. Search for High Dielectric Photochromic Solutions

The host dielectric fluid selected by NASA for use on the first GFFC mission was a silicone (Dow-Corning 200 fluid). It displays a number of favorable characteristics including excellent compatibility with the photochromic compound. Although the silicone fluid has proven the most desirable for GFFC related experiments thus far, there is a potential need for a solvent with an even higher dielectric constant. This might become important for future experiments, as theoretical work at NASA indicates that a stronger simulated gravity is desirable for the AGCE. The most practical way to achieve this is to find suitable dielectric liquids with high dielectric constants and which could satisfy the many other physical properties required. Also, the liquid has to be compatible with a photochromic material and meet the safety standards involved with manned space flight.

3.1 Potential High Dielectric Fluids

The first step in the search for high dielectric photochomic solutions was to develop a list of selected liquids with relatively high dielectric constants. Initially this was accomplished with the aid of dielectric constant data listed in published literature and from general recommendations made by Dr. R. L. Hummel of the University of Toronto who has done research with flow visualization techniques. A number of other factors had to be considered to determine whether or not a particular liquid held any potential for the space experiments. Those included such things as viscosity, melting and vaporization points, thermal conductivity, refractive index, and the rate of change of refractive index with a change of temperature. Factors involved with manned space flight safety requirements include flammability and toxicity.

Requirements for a modest viscosity excludes most of the dielectric oils used in transformers and coils. While most of the high dielectric organic solvents were probably within an acceptable range of viscosity, the Dow Corning silicone fluid is highly advantageous in this respect because the viscosity can be accurately controlled over a very broad

range. The kinematic viscosity range for the Dow Corning fluid is from a very non-viscous .65 centistokes to a highly viscous 100,000 centistokes.

The thermal conductivity as well as other thermal characteristics of the fluid probably is not generally a limiting factor in selecting a dielectric host fluid, but must be known in order to accurately analyze the temperature field gradients produced during various phases of the GFFC experiment. While the thermal characteristics of most fluids can be found in the literature, the effects, if any, of anticipated small concentrations of photochromic material on these properties are reasonably expected to be easily accommodated.

The refractive index of a fluid is not a limiting factor so long as the experimental apparatus error budget takes the index into account. Ideally, a fluid's refractive index would match that of the transparent outer hemisphere of the GFFC. Although that is not necessary it does simplify fabrication of the inner surface.

The change in refractive index with a change in temperature is important. This information will be needed to quantitatively analyze temperature fields in the experiments if the decision is made to collect the large amount of data required to do so. Measurements such as these, however, should be made, only after a final photochromic solution of a given concentration has been selected since the refractive index of a solution is affected by the concentration of solute.

Unfortunately many of the potential dielectric solvents are somewhat toxic and a few are flammable. Depending on the exact safety requirements for the Spacelab mission, some solvents would have to be excluded on the basis of being unsafe for manned space flight in the event of an accident. Those fluids displaying highly undesirable properties will be pointed out later in this report. It should be noted that while some items may be undesirable for space applications, this does not exclude them from being useful in preliminary earth-bound experiments.

Finally, and perhaps most importantly, the particular fluids of interest must be compatible with the chosen photochromic (the selection of the most effective photochromic will be discussed later). Although

a photochromic's compatibility with a particular liquid is somewhat chemically unpredictable, the liquids chosen were generally nonpolar, organic solvents since most of the spiropyrams and other related photochromics are insoluble in water and certain other polar solvents. Most of the solvents tested, along with their dielectric constants (from the literature), are listed in Table 2.

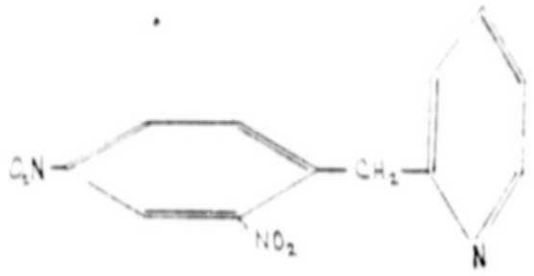
3.2 Potential Photochromics Selected

In addition to searching for a more appropriate solvent, it was felt that the photochromic material chosen for the GFFC, a spiropyran abbreviated TNSB, might not work effectively in liquids other than the silicone fluid. A large number of spiropyrans and related compounds have been identified in the literature and many have been known to display photochromic properties in various solvents. However, since the effects a particular solvent may have on a compound's photochromic properties are often chemically unpredictable, a systematic experimental survey was necessary in order to determine the most effective combination.

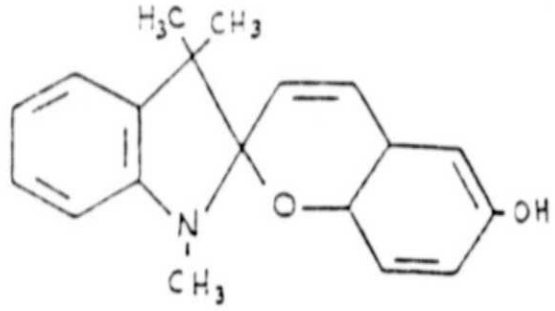
During a search for potential photochromics, only two compounds of interest were found to be commercially available. These included 2-(2,4-Dinitrobenzyl) Pyridine (abbreviated DNBP) and 1',3',3'-Trimethyl-6-Hydroxyspiro-[2H-1-Benzopyran-2-2'-Indoline] (abbreviated THSB). The chemical structures are shown in Figure 1. Both of these compounds were available through Eastman Kodak Chemical Company. A third compound, the originally used TNSB, was not commercially available and had to be acquired from a non-commercial lab. Although many other potential photochromics have been identified in the literature, they are not available commercially and would consequently have to be synthesized in order to be tested for their effectiveness in different dielectric fluids. Synthesis of spiropyrans and related organic photochromics is often a complicated and costly process and is therefore unfortunately out of the scope of this study.

TABLE 2. CANDIDATE SOLVENTS

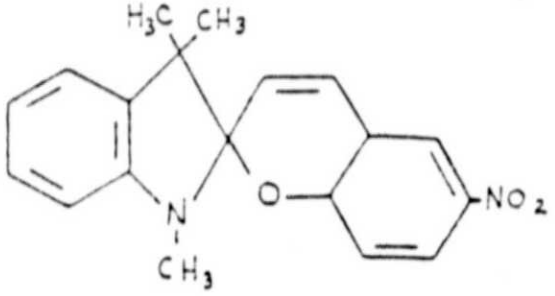
FLUIDS	DIELECTRIC CONSTANT
Cyclohexanol	15
Cyclohexanone	18.5
Acetone	20.7
Chloroform	5
Methanol	33
Decalin (Decahydronaphalene	-
Ethanol	20
Ethyl Acetate	6.1
Ethylene Glycol	37
Propylene Glycol	35
Furfural	41
Benzaldehyde	-
o-Dichlorobeyzene	-
2 - Octanone	-
3 - Heptanone	-
Benzoyl Chloride	29
Glycerol	42.5



DNBP



THSB



TNSB

Figure 1. Chemical Structures of the Three Photochromics Tested

3.3 Combinations of Photochromic and Host Fluids

Following the selection of a number of potential dielectric fluids and photochromic compounds, solutions were made using every possible fluid-photochromic combination. The solutions initially prepared were approximately 0.05 to .1% by weight. They were quantitatively accurate only to an estimated factor of two because measurements to be made at this stage were strictly qualitative since the primary concern was to determine which solutions displayed any photochromic activity when irradiated with UV light. The source of UV radiation for the initial testing was a Soligor MK-6A photo flashlamp. Solutions showing any degree of reversible color change were selected for further study. The properties analyzed in these later studies included relative photochromic effectiveness, effects of aging, dielectric constant, and specific resistivity of the solutions.

An important and almost immediate observation made concerning the photochromic compatibility of the various fluids and compounds was that none of the solutions containing either the THSB or the DNBP photochromic displayed an acceptable degree of photochromic activity during the initial testing. In all cases the THSB photochromic produced deeply colored solutions with the various fluids even prior to irradiation with UV. The DNBP photochromic normally produced somewhat colorless solutions but the only ones displaying any detectable photochromic properties were silicone fluid and ethanol. However, the darkening of even these solutions was hardly detectable and extremely short lived and therefore could not be considered of any value to the project. It is possible that each of these two photochromics could have been more effective at supercooled temperatures, but since the GFFC experiment will be run at room temperature and above it was concluded that the TNSB, the third photochromic, would be the best choice for the GFFC and related experiments. For this reason, all photochromic solutions considered past this stage will contain the TNSB photochromic. Table 3 gives relative photochromic compatibility with TNSB.

It was noticed that some of the effective solutions began to yellow and degrade after only a week or so when kept sitting out in the open in

TABLE 3. SUMMARY OF RELATIVE SOLVABILITY OF PHOTOCHROMIC AND SOLVENT PAIRS

Fluid	Photochromic Compatibility
Cylohexanol	Fair
Cyclohexanone	Good
Acetone	Good
Chloroform	Good
Methanol	Poor
Decahydronaphtnalene (Decalin)	Good
Ethanol	Fair
Ethyl Acetate	Good
Ethylene Glycol	None
Propylene Glycol	Very Poor
Glycerol	Insoluble
Furfural	None
Benzaldehyde	None
o - Dichlorobenzene	Good
2 - Octanone	Good
3 - Heptanone	Fair
Benzoyl Chloride	None

clear glass containers. This phenomena was of particular interest since any space-bound solutions would have to be prepared and stored for some time prior to the mission. Since the most obvious cause for this degradation was the 160 watt overhead 60 cycle flourescent lighting (4 ft distance), an experiment was devised to determine how important light was in the degradation process of some of the organic photochromic solutions. New solutions were made for each of the original solutions that displayed the yellowing or degradation. Then a sample of each solution was placed under continuous (24 hrs.) lighting as previously mentioned, while a second sample of each was placed under partial lighting (approximately 9 hrs. daily), and finally a third sample was stored in darkness. As expected, the samples exposed to continuous lighting showed signs of aging after only one to two weeks. Many of these solutions became completely ineffective photochromically after an additional two to four weeks. The samples exposed to partial lighting underwent a similar aging process which took two to three times as long. Though some of the solutions stored in the dark displayed some yellowing and aging, this occurred after a much greater time than those stored in the light required. Generally six to eight weeks were necessary for even a light yellowing to occur in the solutions stored in the dark.

It is important to note that this experiment was conducted at room temperature (approximately 23-25C) and most photochromics, as is the case for photosensitive materials in general, are affected by temperature as well as light. Like photographic film, the effective lifetime of photochromic solutions can be significantly increased by storing in a cold place. It is recommended, therefore, that photochromic solutions in general be stored in light-tight, and if possible, refrigerated areas when not in use. Interestingly, two solutions, the silicone fluid-TNSB and the ethyl acetate - TNSB solutions, showed little if any aging effects when stored from six months to a year under the same flourescent lighting conditions. However, these same solutions were rendered quickly ineffective when exposed too long to a strong UV source such as sunlight or a high pressure mercury vapor discharge lamp.

3.4 Electrical Measurements

3.4.1 Dielectric Measurement Device Constructed

After the compatible dielectric fluids were chosen, the actual dielectric constants had to be determined for the individual fluids as well as for the fluids after the addition of the photochromic material. Dielectric constant measurements were made by SAI in the following manner: A variable air dielectric capacitor was adjusted to 100 picofarads as measured on a laboratory constructed capacitance bridge. The capacitor was then immersed in the fluid and the capacitance was again measured. Since the capacitance is directly proportional to the dielectric constant and the dielectric constant of air is 1.0, the ratio of the measured capacitances is equal to the dielectric constant of the fluid. At least in the case of Dow Corning silicone fluid, the experimental values obtained were relatively accurate when compared to known values. Later, a Liquid Reference Cell Model LRC-1 manufactured by Balsbaugh, Inc. (See Appendix) was acquired which allowed for more precise and easier measurements using the same capacitance bridge and calculations.

3.4.2 Dielectric Measurements on Photochromic Solutions

Following the construction of the device to measure the dielectric constant of fluids, SAI proceeded to make some initial measurements in order to determine the accuracy of the instrument. The first fluids selected, the 1 centistoke and 20 centistoke viscosities of the Dow Corning 200 Silicone Fluid, gave results surprisingly close to the published figures. The 20 centistoke fluid measured 2.6 and the 1 centistoke fluid measured 2.25. However, when each of the supposedly high dielectric solvents were tested for dielectric constant, it was discovered that all of the fluids were conductive and the dielectric constant was not even measurable on the devices constructed. Since some of the dielectric solvents were not photochromically compatible, they were not measured; all others, however, were. It quickly became obvious that the published dielectric constants were for very highly purified liquids under very ideal conditions. Although the solvents acquired were normally of the highest

grades available, the actual lot analysis available for some the solvents (See Appendix) showed them to be far too impure to function as a dielectric. For example, a certified grade of acetone proved to be actually 99.5% pure containing such impurities as water, methanol, isopropanol, and in smaller concentrations, acetic acid, ammonia, and acetaldehyde. Even deionized water which is supposed to have a dielectric constant of about 81 could not be found commercially pure enough to measure.

Since none of the solvents except the silicone fluid demonstrated any dielectric character, their respective photochromic solutions, likewise, showed no potential of being dielectrically acceptable. Measurements were made, however, to determine the effect that TNSB has on the dielectric constant of silicone fluid. The following results were obtained.

TABLE 4. RESULTS OF DIELECTRIC CONSTANT MEASUREMENTS

Fluid	Dielectric Constant
20 centistoke (no photochromic)	2.6
.02% TNSB	2.47
.04% TNSB	2.42
1 centistoke (no photochromic)	2.25
.02% TNSB	1.92
.04% TNSB	1.87

As might be expected, the addition of photochromic caused a slight decrease in the dielectric constant but certainly not a serious decrease. It is not known, however, if the decrease was due entirely to the photochromic or possibly to impurities in the photochromic. The purity of the TNSB is unknown.

From the unfortunate results obtained from the other organic solvents, it is suggested that some of the more promising solvents be acquired (if possible) at extremely high purity. Even if the necessary dielectric constant is obtained for a fluid, it is not known whether the effects of the TNSB will be as minimal as they are in the silicone fluid.

3.4.3 Measuring Specific Resistivity of Photochromic Solutions

In addition to making precise measurements of dielectric constant, it became important to determine the volumetric conductivity or specific resistivity of the dielectric fluids and how this was affected by the addition of TNSB photochromic. The equipment used to make these measurements included a Liquid Reference Cell Model LRC-1 from Balsbaugh, Inc., and a High Voltage Power Supply Model 244 from Keithley Instruments, an Electrometer Model 610C also from Keithley Instruments (See Appendices).

The specific resistivity of the fluid was computed from the equation: Rsp = KRx, where K = 11.3 Ca.Ca, the capacitance of the LRC-1 with air dielectric was measured to be 91.0 picofarads. Rx was measured by the volt-ampere method. The LRC-1 filled with fluid was connected in a series circuit with 1000 volts DC and an Electrometer to measure the current through the cell. Rx was then computed from the equation:

$$Rx = \frac{\text{Vsource - Vinput drop}}{\text{I Measured}} .$$

Since, as previously mentioned, the organic solvents tested did not have a measurable dielectric constant, the specific resistivity measurements were performed on the different available viscosities of the dielectric silicone fluid. The following results were obtained:

TABLE 5. RESULTS OF SPECIFIC RESISTIVITY TESTS

Fluid	Specific Resistivity
Dow-Corning 200 Silicone Fluid	
20 cs. (no photochromic)	1.572×10^{13} ohm - cm
20 cs .02% TNSB	1.48×10^{13} ohm - cm
20 cs .04% TNSB	1.27×10^{13} ohm - cm
1 cs (no photochromic)	5.038×10^{13} ohm - cm
1 cs .02% TNSB	1.37×10^{11} ohm - cm
1 cs .04% TNSB	1.065×10^{11} ohm - cm

No change was observed in the specific resistivity when the fluid was briefly exposed to UV radiation while the test cell was connected to the measuring equipment.

4. UV Light Source

The weight and power input requirements of an available mercury vapor lamp was examined. The lamps used in specific laboratory tests were a Philips Spectral Low Pressure Hg-vapor lamp and a Philips Spectral High Pressure Hg-vapor lamp. The power supplies used were an Ealing Spectral Lamp Supply and an SAI laboratory capacitance discharge circuit. As anticipated beforehand, the low pressure lamp drew considerably less power than the high pressure lamp, but emitted too little radiation in the proper UV range to obtain observable response in any of the various photochromic solutions.

Efforts were made to reduce the input power requirements of the Philips high pressure lamp which in earlier tests already had proven capable of darkening the photochromic. One major problem had to be overcome. It became apparent by experiment that high pressure lamps required a considerable warm-up period before they draw full power and produced the rated amount of UV radiation. This period is necessary for the lamp to attain threshold pressure and the spectral output increases as the pressure within the lamp increases from thermal effects. Depending upon other factors, this warm-up time normally lasted several minutes. Unless this could be avoided, the lamp would have had to remain on continuously throughout most of the experiment. This would have used far in excess of the allotted steady state power for the Spacelab experiment. In addition, it may have presented a slight heating problem. When workers in the SAI optics lab attempted to decrease this warm-up time by increasing the initial voltage or current via capacitor discharge, the quartz tube containing the pressurized metal vapor would crack at one of the electrode ends due to differential expansion between the glass and the electrode. This allowed the high pressure vapor to escape into the outer cylindrical glass envelope, causing the discharge tube to cease functioning.

After an effort was made to alter the nature of the input power, such as maintaining the lamp on a trickle lower voltage, it was concluded that a power supply much like the Ealing Universal Spectral Lamp Supply would be required to perform the necessary tasks. Since this particular

power supply was somewhat large for space applications and had a weight of slightly over nine kg., it was felt that a special power supply would have to be designed and constructed to comply with the Spacelab requirements.

During this time, SAI continued to acquire all the information available concerning commercially-built UV sources and passed this information on to NASA as it became available. About two months into the study, however, NASA notified SAI that Aerojet Corporation, the prime contractor for construction of the GFFC, had selected a commercially available flash lamp which they felt had sufficient output to be used as the UV light source in the GFFC. While the mercury vapor lamp may still prove to be a useful tool in unrestricted, earth-bound experiments, this ended SAI's role in this effort. However, SAI remains concerned about the ability of the proposed flashlamp to "imprint" various high resolution patterns in the alloted exposure times and suggests this may again arise as a problem area.

5. Analysis of Optical Techniques

Several opportunities present themselves regarding potential improvement of the optical apparatus. Two of these areas are discussed below. Others are being examined under contracts with Aerojet, TAI and in-house NASA. SAI has monitored some of this activity and detects no objectionable findings.

5.1 Potential Use of Fresnel Lenses in GFFC

The current optical design for the GFFC employs a number of expensive glass elements. These are necessary to achieve required resolution over a 90^{o} spherical triangle on the sphere's surface. Early in the study, however, SAI felt that lightweight, relatively inexpensive Fresnel lenses may be able to replace complex, aspherical optical elements in the GFFC and the AGCE. Very low F-numbers may be attained with Fresnel lenses. They are Flat, low volume and can be constructed of lightweight plastic. A series of experiments was conducted to determine the resolution capabilities of low F-number Fresnel lenses. In one case, a matched pair of F 0.7 Fresnel lenses was used to focus test rulings of various spatial frequencies unto photographic film, as shown in Figure 2. A resolution of better than 4 line pairs per mm was easily achieved. This exceeds GFFC requirements. Further experimentation might have proven the resolution to be even better, but effort was discontinued due to a NASA shift of interest away from this area.

5.2 Acquisition and Optical Inspection of Glass Domes

SAI acquired optical quality glass hemispheres for the construction of additional models of the GFFC-AGCE experimental arrangement. Two hemispheres were obtained from the Precision Lapping Company. The hemispheres were five inches outside diameter with .118 inch thick walls and constructed of high quality optical crown glass. The hemispheres had a dispersion of 58.6 and a refractive index of 1.523. One hemisphere was delivered immediately to the NASA experimentors while the other was retained in order that optical analysis could be performed in the SAI Optics Laboratory. The hemisphere was tested by reconstructing high frequency rulings that had been passed through the hemisphere normal to the surface. A HeNe laser and

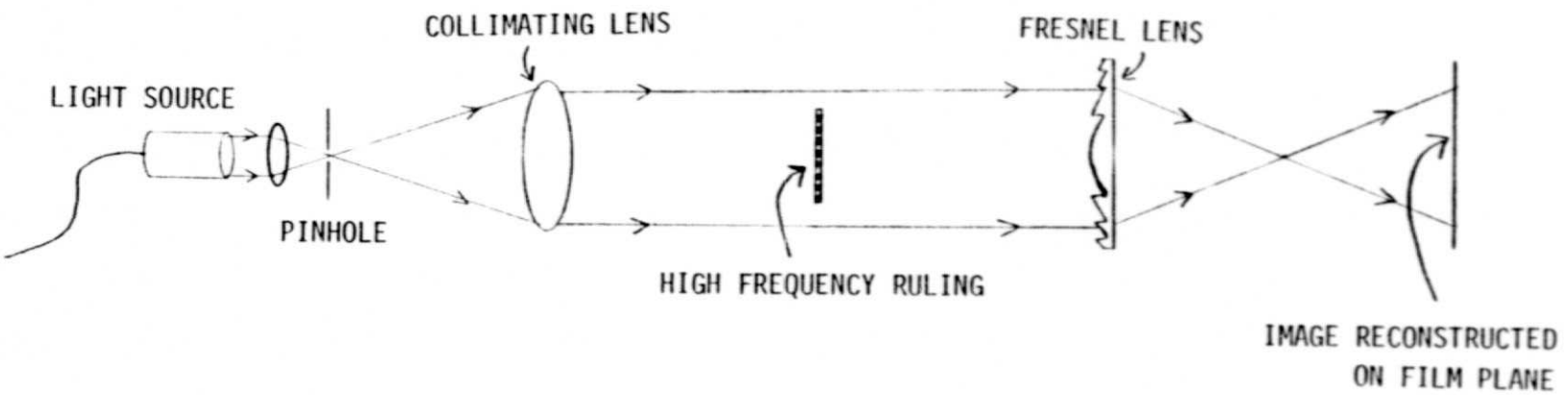


Figure 2. Fresnel Resolution Experiment Using One Fresnel Lens

a pair of precision Fourier lenses were used in the set-up. The results were compared to images produced through hemispheres with known imperfections. Figure 3 is an image reconstructed through the quality hemisphere. Figure 4 is an image reconstructed through an imperfect hemisphere. The experimental set up used in the optical analysis is illustrated in Figure 5.

This is the recommended test procedure for future work because it relates directly to the retroreflection concept originally proposed.

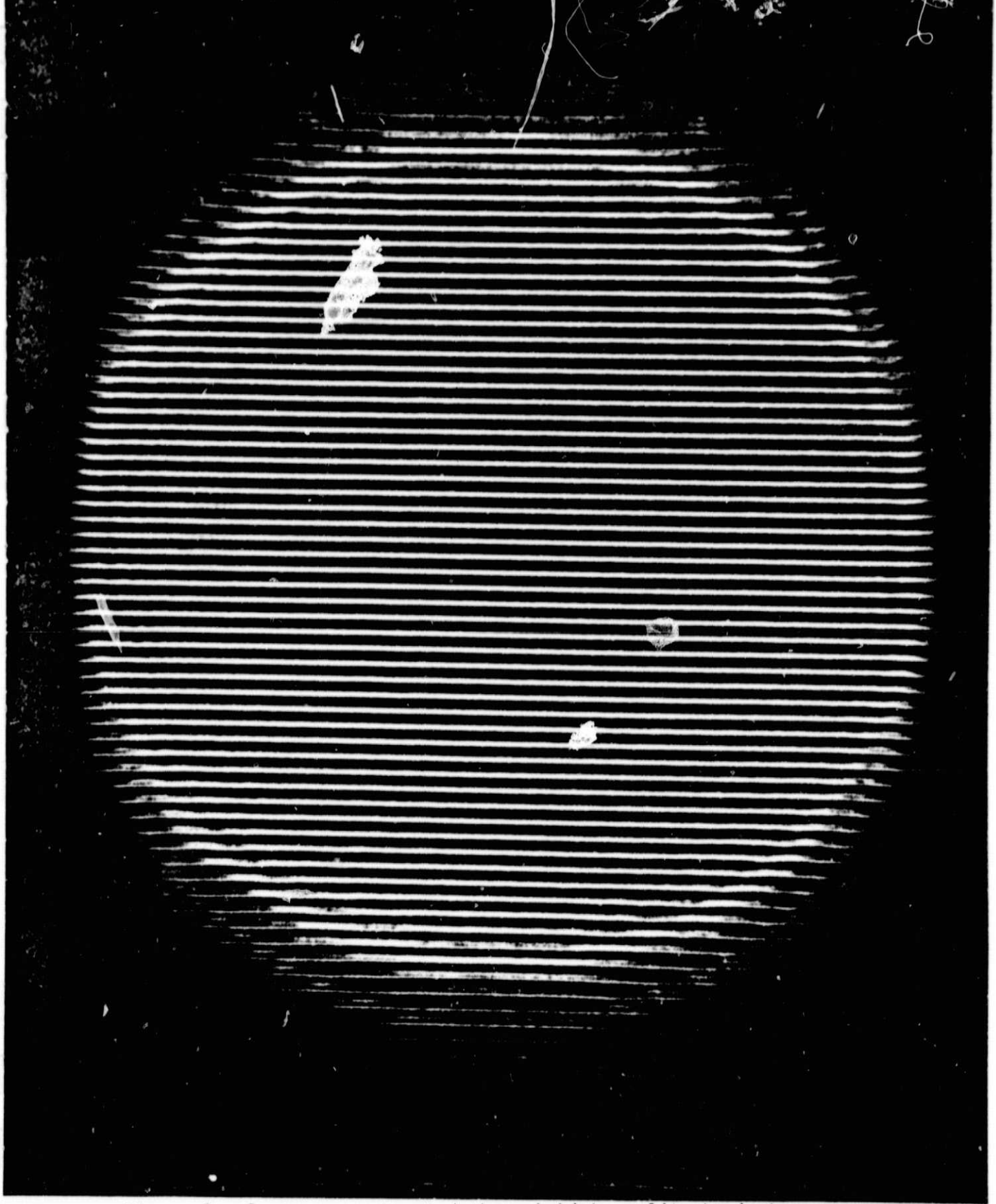


Figure 3. Image reconstructed through high quality hemisphere.

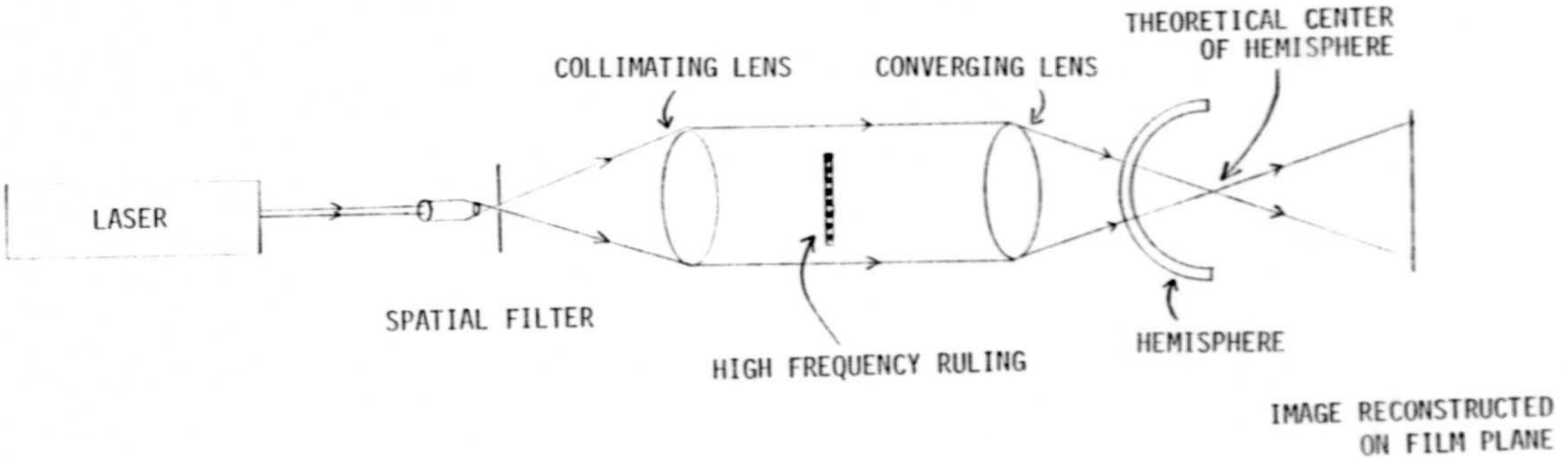


Figure 5. Optical Inspection of Hemispheres

Appendix I - Detailed Descriptive Information on Selected Dielectric Solvents

Since only a small amount of photochromic solute is necessary to produce a satisfactory photochromic solution, the host fluid itself is primarily responsible for determining the final electrical properties of the resulting solution. In order to more fully understand the results of the various electrical measurements conducted during the study (whether these results are considered acceptable or not), it is important to know something about the purity of the solvents used. The various purity grades given to commercially produced chemical and what these grades mean are listed below. Also included are the actual lot analyses of some of the solvents used as well as the purity grades of the individual solvents whose complete analyses were not available. Those solvents which were not compatible with the photochromic are not included.

PURITY GRADES

Certified - "Meet or surpass latest American Chemical Society standards for purity (the only universally accepted specification for reagents). The purity is detailed by an actual lot analysis on each label."

Reagent Grade - "Meets maximum limits of significant impurities as stated. Does not have specific lot analysis."

Laboratory Grade - "Equivalent in purity to United States Pharmacopeia (USP) and National Formulary (NF) listings."

Purified Grade - "Designates chemicals of quality where there are no official standards."

Practical Grade - "Sufficiently high quality for use in many syntheses and other applications."

Technical Grade - "Selected commercial grades, scrupulously clean, and of reasonable chemical purity."

Acetone (Certified Grade)

CH_3COCH_3	F.W.	58.08
Color (APHA)		5
Density (g/ml) at 25°C		.7851
Boiling Point (First drop to drypoint)		56.1°C ± 1°C
Boiling Range		56.0° - 56.3°C
Assay (CH_3COCH_3)		99.5%
Residue after evaporation		.0002%
Solubility in water		P.T.
Acidity (as CH_3COOOH)		.002%
Alkalinity (as NH_3)		.0002%
Aldehyde (HCHO)		.0004%
Methanol (CH_3OH)		.02%
Substances Reducing Permanganate		P.T.
Water (H_2O)		.5%
Isopropyl Alcohol		.01%
Flash Point		0°F

Ethyl Acetate (Certified Grade)

$CH_3COOOC_2H_5$	F.W.	88.11
Color (APHA)		5
Acidity (as CH_3COOH)		.001%
Boiling Point		77.2°C ± .1°C
Boiling Range (First Drop to Drypoint)		76.9 - 77.2°C
Density (gm/ml) at 25°C		.894
Foreign esters		P.T.
Residue after evaporation		.0006%
Substances darkened by Sulfuric Acid		P.T.
Water (H_2O)		.05%
Flash Point		24°F

Methanol (Certified Grade)

CH_3OH	F.W.	32.04
Appearance		Clear and Colorless
Acetone, Aldenhydes		(About .001%) P.T.
Boiling Point		64.6°C ± .1°C
Boiling Range (First Drop to Drypoint)		64.6° - 64.9°C
Water (H_2O)		0.05%
Residue after Evaporation		2 ppm
Alkalinity (as NH_3)		1 ppm
Acidity (a CH_3COOH)		0.001%
Substances Reducing $KMnO_4$		P.T.
Solubility in Water		P.T.
Substances darkened by H_2SO_4		P.T.
Color (APHA)		5
Flash Point		50°F

FLUID	PURITY GRADE
Cyclohexanol	Reagent
Cyclohexanone	Purified
Chloroform	Laboratory
Decahydronaphthalene (Decalin)	Purified
3-Heptanone	Practical
2-Octanone	Practical
Erthanol	Reagent

LIQUID REFERENCE CELL

FOR MEASUREMENT OF-

Dielectric constant
Dissipation factor
Loss factor
Resistivity

ON SUCH LIQUIDS AS-

Benzene
Silicone fluids
Other liquid dielectrics

MODEL LRC-1

Primarily used for the measurement of dielectric constant and dissipation factor of benzene and silicone fluids used in liquid displacement tests per ASTM D 1531. The unit meets the requirements of ASTM D 176 and Manufacturing Section 17,000 Section 1168 of the Western Electric Company. Construction is of gold plated brass with Teflon insulation, with 300 series stainless available on special order. A coaxial connector is provided for guard and guarded terminal connection, and a plug receptical is provided for outer electrode connection. A thermometer may be inserted in the center electrode for precise determination of the temperature of the liquid under test. Air capacitance nominally 50 pf, with 50 mil electrode spacing. Volume of fluid required 25 cc. The unit is easily disassembled for cleaning.

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APPENDIX III
SPECIFICATIONS

OUTPUT:

Voltage: -200 to -2200 volts in 20-volt steps

Current: 10 milliamperes maximum

Polarity: Negative with respect to chassis

ACCURACY: ±1% of dial setting

RESOLUTION: A 0-25 volt "Trim" potentiometer permits interpolation between steps with a resolution of better than 100 millivolts.

STABILITY: ±0.005% per hour after a two-hour warm-up; ±0.01% the first hour or in subsequent 8-hour periods after a one-hour warm-up.

LINE REGULATION: ±0.001% for a 10% change in line voltage.

LOAD REGULATION: ±0.001% for a 5-milliampere load change.

RIPPLE AND NOISE: Less than 0.5 millivolt rms above 5 Hz.

OVERLOAD: Electronic current limiting with automatic recovery.

METER: Provides check on output voltage.

CONNECTORS: Output (on rear) MHV series (UG-931/U)

POWER: 105-125 or 210-250 volts (switch-selected); 50-60 Hz; 90 watts.

DIMENSIONS: 6-1/4" high x 8-7/8" wide x 14-7/8" deep (158 x 225 x 378 mm)

WEIGHT: net weight, 13 pounds (6,0 kg).

ACCESSORIES FURNISHED: Mating Connector (MHV series, JG-932A/U)

APPENDIX IV
SPECIFICATIONS

AS A VOLTMETER:

RANGE: .001 volt full scale to 100 volts in eleven 1x and 3x ranges.

ACCURACY: ±1% of full scale on all ranges exclusive of noise and drift.

ZERO DRIFT: Less than 1 millivolt per 24 hours, less than 150 microvolts per °C after 30-minute warm-up.

METER NOISE: ±25 microvolts maximum with input shorted on most sensitive range.

INPUT IMPEDANCE: Greater than 10^{14} ohms shunted by 20 picofarads. Input resistance may also be selected in decade steps from 10 to 10^{11} ohms.

AS AN AMMETER:

RANGE: 10^{-14} ampere full scale to 0.3 ampere in twenty-eight 1x and 3x ranges.

ACCURACY: ±2% of full scale on 0.3 to 10^{-11} ampere ranges using the smallest available multiplier setting; ±4% of full scale on 3×10^{-12} to 10^{-14} ampere ranges.

METER NOISE: Less than $\pm 3 \times 10^{-15}$ ampere.

OFFSET CURRENT: Less than 5×10^{-15} ampere.

AS AN OHMMETER:

RANGE: 100 ohms full scale to 10^{14} ohms in twenty-five linear 1x and 3x ranges.

ACCURACY: ±3% of full scale on 100 to 10^{10} ohm ranges using the largest available multiplier setting; ±5% of full scale on 3×10^{10} to 10^{14} ohm ranges.

AS A COULOMBMETER:

RANGE: 10^{-13} coulomb full scale to 10^{-5} coulomb in seventeen 1x and 3x ranges.

ACCURACY: ±5% of full scale on all ranges. Drift due to offset current does not exceed 5×10^{-15} coulomb per second.

AS AN AMPLIFIER:

INPUT IMPEDANCE: Greater than 10^{14} ohms shunted by 20 picofarads. Input resistance may also be selected in decade steps from 10 to 10^{11} ohms.

OUTPUTS: Unity-gain output and either voltage or current recorder output.

UNITY-GAIN OUTPUT: At dc, output is equal to input within 10 ppm, exclusive of noise and drift, for output currents of 100 microamperes or less. Up to one milliampere may be drawn for input voltages of 10 volts or less. Output polarity is same as input polarity.

VOLTAGE RECORDER OUTPUT: ±3 volts for full-scale input. Internal resistance is 3 kilohms. Output polarity is opposite input polarity.

Gain: 0.03, 0.1, etc., to 3000.

Frequency Response (within 3 db): dc to 40 kHz at a gain of 1 and lower, decreasing to dc to 100 Hz at maximum gain. Full output response limited to 3 kHz on any gain.

Noise: Less than 3% rms of full scale at gain of 3000, decreasing to 1% at gains below 100.

CURRENT RECORDER OUTPUT: ±1 milliampere for full-scale input, variable ±5% with 1400-ohm recorders.

GENERAL:

POLARITY: Meter switch selects left-zero (positive or negative) or center-zero scales. Output polarity is not reversed.

LINE STABILITY: A 10% change in line voltage will cause less than a 10-microvolt meter deflection on all ranges.

CONNECTORS: Input: Teflon-insulated UHF type; ground binding post. Voltage or current output: Amphenol 80-PC2F. Unity-gain output: binding posts.

POWER: 105-125 or 210-250 volts (switch selected), 50-1000 Hz, 10 watts.

DIMENSIONS, WEIGHT: Model 610C: 10-1/2" high x 6-5/8" wide x 10" deep; net weight, 12 pounds. Model 610CR: 5-1/4" high x 19" wide x 10" deep; net weight, 12 pounds.

ACCESSORIES SUPPLIED: Mating input and output connectors; binding post adapter.