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A FAR ULTRAVIOLET POLARIZATION ANALYZER FOR ROCKET USE

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ABSTRACT

A rocket version of a far ultraviolet polarization analyzer has been constructed to measure the polarization of resonantly scattered sunlight. The rotating, 8-plate, LiF polarization analyzer has principal transmittances which vary from $k_1 = 0.088$ and $k_2 = 0.0037$ at H Lyman alpha to $k_1 = 0.623$ and $k_2 = 0.075$ at 2500Å. The region from 1200 to 2000Å is divided into four intervals by using filters of CaF_2, BaF_2, and AL_2O_3 in conjunction with the "solar blindness" of the CsI photocathode. The calculated polarizations, which are a direct consequence of the Zeeman effect, are given for some of the ultraviolet multiplets which could contribute to the ultraviolet day airglow in planetary atmospheres. Departures from the calculated polarizations may be due to the effects of multiple scattering, collisional excitation, and hyperfine structure. The observed polarization of the sum of the lines which constitute a multiplet is dependent upon the relative population (a measure of the temperature) of the ground states of the multiplet.

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CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (con't)

TABLES

A FAR ULTRAVIOLET POLARIZATION ANALYZER FOR ROCKET USE

INTRODUCTION

There are two quantities which are important for understanding the basic physical processes which are responsible for the excitation and subsequent spectral emission from atoms and molecules. These are the intensity (both total as well as the distribution with wavelength) and the polarization. On the atomic scale generally all radiation is polarized whereas on the macroscopic scale this is not necessarily true. Much work has been devoted to measurements of the former, while very little work has been reported of the latter, particularly with regard to the far ultraviolet from 1100-2000Å. This is particularly true of the measurements which have been made of the far ultraviolet day and night airglow from rockets and satellites.

The work reported here is concerned with the instrumentation which was developed and flown on an Aerobee 150 rocket from White Sands, New Mexico on August 29, 1966 for the purpose of measuring the polarization and intensity, as a function of altitude, of the far ultraviolet dayglow emission from 1200-2000Å. The results on Lyman alpha have been published by Heath,[1] while those for the 1304Å and 1356Å multiplets of OI, and the tentatively identified Vegard-Kaplan and Lyman-Birge-Hopfield bands in the 1435-2000Å are being prepared for publication.

POLARIZATION OF RESONANCE SCATTERING

For single resonance scattering the polarization or anisotropy of the scattered radiation is due to the effect of light on an isotropic medium. A light beam is anisotropic in that there are no vibrations of the electric vector in the direction of propagation. The light incident on a medium will interact preferentially with those atoms or molecules which have certain orientations with respect to the incident beam. As a consequence, light emitted due to absorption of a light ray may be partially or completely polarized. In the resonance scattering of linearly polarized light one has transitions in which the magnetic quantum number M remains constant ($\Delta M = 0$). This can cause a preferential population of the magnetic sub levels so that $I_\pi \neq I_\sigma$ ($I_\pi = I_\sigma$ for unpolarized radiation). The intensity of the line is equal to the sum of the π and σ components which are emitted when the magnetic quantum number changes by ±1 and 0 respectively. The polarization is defined such that

$$P_p = \frac{I_\pi - I_\sigma}{I_\pi + I_\sigma} \tag{1}$$

The use of the description based on the Zeeman splitting of levels is justified by Heisenberg's Principle of Spectroscopic Stability[2] which states that if a certain degree of polarization is obtained when there is a strong field in the direction of the electric vector of the exciting light then the same result is obtained on decreasing the field slowly to zero.*

Since the amount of polarization of resonance radiation depends upon the quantum number J (total angular momentum) in the excited and ground states one can use the formulas for the intensities of Zeeman components to calculate the degree of polarization. Feofilov[5] has calculated a general expression for

*For a general discussion on the polarized emission of light see the work of Mitchell and Zemansky[3], and Feofilov[4].

the degree of polarization resulting from resonantly scattered linearly polarized radiation as a function of J where J_1 and J_2 are the ground and excited states respectively. It is assumed that observations are made at 90° to the incident beam.

Case I $\Delta J = 0$ ($J_1 = J_2$)

$$P_p = \frac{(2J + 3)(2J - 1)}{8J^2 + 8J - 1} \tag{2}$$

Case II $\Delta J = +1$ ($J_1 = J$, $J_2 = J + 1$)

$$P_p = \frac{(J + 2)(2J + 5)}{14J^2 + 23J + 10} \tag{3}$$

Case III $\Delta J = -1$ ($J_1 = J$, $J_2 = J - 1$)

$$P_p = \frac{(J - 1)(2J - 3)}{14J^2 + 5J + 1} \tag{4}$$

The function $P_p(J)$ is shown in fig. 1 for the cases $\Delta J = 0, \pm 1$. Notice that Case I by virtue of the selection rule $\Delta J = 0$ holds for the Q-branch of a molecular band. Similarly Case II holds for the R-branch ($J + 1 \rightarrow J$), and Case III holds for the P-branch ($J \rightarrow J + 1$).

If the excitation is due to solar radiation then the degree of polarization, P_n, observed perpendicular to the solar rays is related to that observed in the case of resonance scattering of linearly polarized light, P_p.

$$P_n = \frac{P_p}{2 - P_p} \tag{5}$$

The function $P_n(J)$ is shown for the three cases, $\Delta J = 0, \pm 1$, in fig. 2. If the nuclear spin produces completely separated hyperfine levels then one can substitute F for J in the preceeding formulas where $\mathbf{F} = \mathbf{I} + \mathbf{J}$, and I is the nuclear spin.

Just as polarized radiation is due to anistropic excitation of an isotropic medium, so is unpolarized radiation produced by the isotropic excitation of this medium. Consequently multiple resonance scattering and collisional excitation such as that produced by photoelectrons leads to the production of unpolarized radiation. Also for an anisotropic distribution of charged particles the degree of polarization of the resultant radiation is dependent upon the energy of the particles.[7]

The polarizations to be expected from the single resonance scattering of solar radiation at 90° to the rays are given in table I for the nitrogen, hydrogen, and oxygen multiplets which have been observed in the day airglow[6,9] in the far ultraviolet, and those of helium, argon, and carbon which may be important in other planetary atmospheres. From this table it is apparent that the degree of polarization varies widely for the lines of a particular multiplet. Furthermore, one must consider the magnitude of the hyperfine splitting produced by nuclear spin. Brandt and Chamberlain[10] have shown that for H-Lyman alpha the $^2S_{1/2}$ - $^2P_{3/2}$ component would have a polarization of 0.254 for completely separated hyperfine levels and of 0.429 in the complete absence of hyperfine structure. Since there are large variations in the polarization among the lines of a multiplet the measured polarization of that multiplet will depend strongly upon the relative population of the ground states of the multiplet if the radiation is produced in an optically thin atmosphere.

For molecules one must know the relative strengths of the P, Q, and R-branches as well as the population distribution in the ground state in order to be able to predict the polarization. Obviously those molecules with strong Q-branches ($\Delta \Lambda = \pm 1$) will exhibit the highest degree of polarization. For very high ground state rotational temperatures $P_n \rightarrow 0.333$ for Q-branches, and 0.077 for the P and R-branches.

INSTRUMENTATION

The far ultraviolet polarization analyzer is shown in fig. 3. It consists basically of a light baffle, followed by a rotating transmission pile-of-plates polarization analyzer,* a filter wheel, a photomultiplier, and its associated electronics. The analyzer with the top and rear side removed, and the filter wheel are shown with the instrument.

The analyzer, based on a design by Walker,[11] consists of eight cleaved plates of LiF which are set at an angle of 30° to the transmission axis. In this arrangement the angle of incidence is 60° which is close to the Brewster angle for Lyman alpha. The plates are set in two opposing groups of four each so that there is no net beam displacement. The individual plates range in thickness from 0.010-0.015 inches. They are cleaved in groups of four, and the groups of four are chosen to make the total thickness of the two groups identical. On the average the total thickness of LiF in an eight plate assembly is about 2.5 mm. The plates are mounted in a holder 4-1/8 × 1 × 1 inches which has a 1/2 inch diameter aperture at both ends.

*Constructed by the Crystal-Solid State Division of the Harshaw Chemical Co.

A geneva action filter wheel* containing no filter, CaF_2, BaF_2, Al_2O_3, and a blank are successively interposed. The analyzer rotates through an angle of 720° for each filter position. The filters provide the short-wavelength cutoff, and the "solar blindness" of the cathode (CsI) of an ASCOP 542G limits the long wavelength response. Consequently the signals from the five filter wheel positions are due to radiation from 1200-2000Å, 1230-2000Å, 1335-2000Å, 1435-2000Å, and the dark current. The signal currents are detected and converted into a telemetry input voltage by a four-decade range switching linear electrometer.** Subtractive techniques are used to isolate the signal in the wavelength intervals 1435-2000Å, 1335-1435Å, 1230-1335Å, and 1200-1230Å.

The instrument flown at White Sands had a field of 4° (0.39×10^{-2} sterad) and a limiting aperture of 0.67 cm^2. A current instrument which is being made ready for flight has a field of 6.7° (0.86×10^{-2} sterad) and an aperture of 1.0 cm^2.

Sections of typical telemetry records are shown in fig. 4. The upper record (a) shows no polarization of Lyman alpha at 90° to the sun. The lower record (B) shows the polarization produced by direct sunlight which is incident at 58° to the photometer axis being scattered off the baffle.

The performance parameters of the polarizer-analyzer combination were obtained by measuring the transmittance H_0 of the parallel pair, and the transmittance H_{90} of the crossed pair. If both are ideal, homogeneous, and non depolarizing, then the following relations hold:

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*The filter wheel photometer was fabricated by the Ray Lee Machine Co.
**Adcole Corp.

$$H_0 = 1/2\,(k_1^2 + k_2^2) \tag{6}$$

$$H_{90} = k_1 k_2 \tag{7}$$

$$k_1 = \frac{\sqrt{2}}{2}\left[(H_0 + H_{90})^{1/2} + (H_0 - H_{90})^{1/2}\right] \tag{8}$$

$$k_2 = \frac{\sqrt{2}}{2}\left[(H_0 + H_{90})^{1/2} - (H_0 - H_{90})^{1/2}\right] \tag{9}$$

where k_1 and k_2 are the major and minor principle transmittances.* The transmittance of the analyzer for unpolarized light is given by:

$$T = 1/2\,(k_1 + k_2) \tag{10}$$

and the degree of linear polarization is given by:

$$P = \frac{(k_1 + k_2)(I_{max} - I_{min})}{(k_1 - k_2)(I_{max} + I_{min})} \tag{11}$$

where I max and I min are the maximum and minimum of the telemetry signals observed during the rotation of the analyzer. The curves for k_1 and k_2 of the flight analyzer are shown in fig. 5. The transmittances of the crossed and parallel pair were measured at the exit slit of a McPherson Model 225 (normal incidence) monochromator using a Hinteregger type windowless hydrogen light source. A special chamber was constructed which made it possible to rotate either the polarizer of analyzer through 360° about the exit beam. The monochromator produced no measurable polarization at 1216Å whereas at 2500Å it was about 1%.

*For a general description and references see Shurcliff.[12]

The measured transmittance of one of the pair is indicated by the curve drawn through the crosses while the circles indicate transmittances calculated using eq. (10). This curve indicates the validity of the assumption of an identical pair. The region of optimum performance of the analyzer can be seen in fig. 7 where k_1/k_2 is plotted against wavelength.

If one makes the very crude assumption that the scattering coefficient for radiation of the blackened baffle is independent of wavelength in the region of 1200-2500Å, then relative sensitivity of the instrument to scattered light is shown in fig. 9. The product of the transmittance of the analyzer, the quantum efficiency of the photomultiplier, and the solar flux* is graphed versus wavelength.

CONCLUSIONS

The measurement of the polarization of resonantly scattered sunlight can provide important information on the processes which are responsible for the excitation of the atoms and molecules which contribute to the airglow. As one moves up through the atmosphere, the appearance of polarized radiation indicates the region of transition from an optically thick to thin atmosphere. The depolarization due to multiple scattering is an extremely sensitive measure of the optical depth above the instrument. In an optically thin atmosphere, the relative importance of resonance scattering to photoelectron or any other non-polarizing collisional excitation for the emission source function can be assessed. One also has information about the population distribution or excitation condition

*See the review by Tousey[13]

of the emitting species in their ground state configuration which may be related to the temperature.

An important advantage of polarization measurements is that one need measure only the ratio of two signals. This is an easy measurement to make compared to the difficulties which one faces in an attempt to make an absolute intensity measurement in the far ultraviolet from rockets of satellites.

The instrumentation which has been described is relatively simple as is the analysis of the data. It should be emphasized that the photometer described produces relatively simple results only if one knows the identity of the emitting species. For this task, the spectrophotometer is best suited.

Table I

Polarization at 90° from sun for single resonance scattering

Atom	Multiplet	J	Wavelength* (Å)	Polarization (P_n)
Helium	$1s^2\ ^1S-2p\ ^3P$	0-1	584	1.00
Argon	$3p^6\ ^1S-4s\ ^1[1/2]$	0-1	1048	1.00
Nitrogen	$2p^3\ ^4S-3s\ ^4P$	3/2-5/2	1199	0.224
		3/2-3/2	1200	0.261
		3/2-1/2	1200	0
	$2p^3\ ^4S-2p^4\ ^4P$	3/2-5/2	1134	0.224
		3/2-3/2	1134	0.261
		3/2-1/2	1134	0
Hydrogen	$1s\ ^2S-2p\ ^2P$	1/2-3/2	1215	0.428
		1/2-1/2	1215	0
Oxygen	$2p^4\ ^3P-3s\ ^5S$	2-2	1355	0.287
		1-2	1358	0.287
	$2p^4\ ^3P-3s\ ^3S$	2-1	1302	0.0073
		1-1	1304	0.198
		0-1	1306	1.00
Carbon	$2p^2\ ^3P-3s\ ^3P$	2-2	1656	0.287
		1-1	1657	0.198
		2-1	1658	0.0073
		1-0	1657	0
		1-2	1656	0.287
		0-1	1656	1.00

*For complete multiplet wavelengths see C. E. Moore.[8]

REFERENCES

1. D. F. Heath, Ap. J. 148, L97 (1967).
2. W. Heisenberg, Zeit f. Phys. 31, 617 (1926).
3. A.C.G. Mitchell and M. W. Zemansky, Resonance Radiation and Excited Atoms, (Cambridge University Press, London, 1934).
4. P. P. Feofilov, The Physical Basis of Polarized Emission, (translation, Consultants Bureau, New York, 1961).
5. Ibid, p. 52.
6. Ibid, p. 40.
7. I. C. Percival and M. J. Seaton, Phil, Trans. Roy, Soc. (London), A251, 113 (1958).
8. C. E. Moore, An Ultraviolet Multiplet Table, (Circ. National Bureau of Standards 488, 1950).
9. W. G. Fastie, H. M. Crosswhite, D. F. Heath, J. Geophys. Res., 69, 4129 (1964).
10. J. C. Brandt, and J. W. Chamberlain, Ap. J. 130, 670 (1960).
11. W. C. Walker, Appl. Opt. 4, 1005 (1965).
12. W. A. Shurcliff, Polarized Light (Harvard University Press, Cambridge, 1962).
13. R. Tousey, Space Science Reviews, 2, 3(1963).

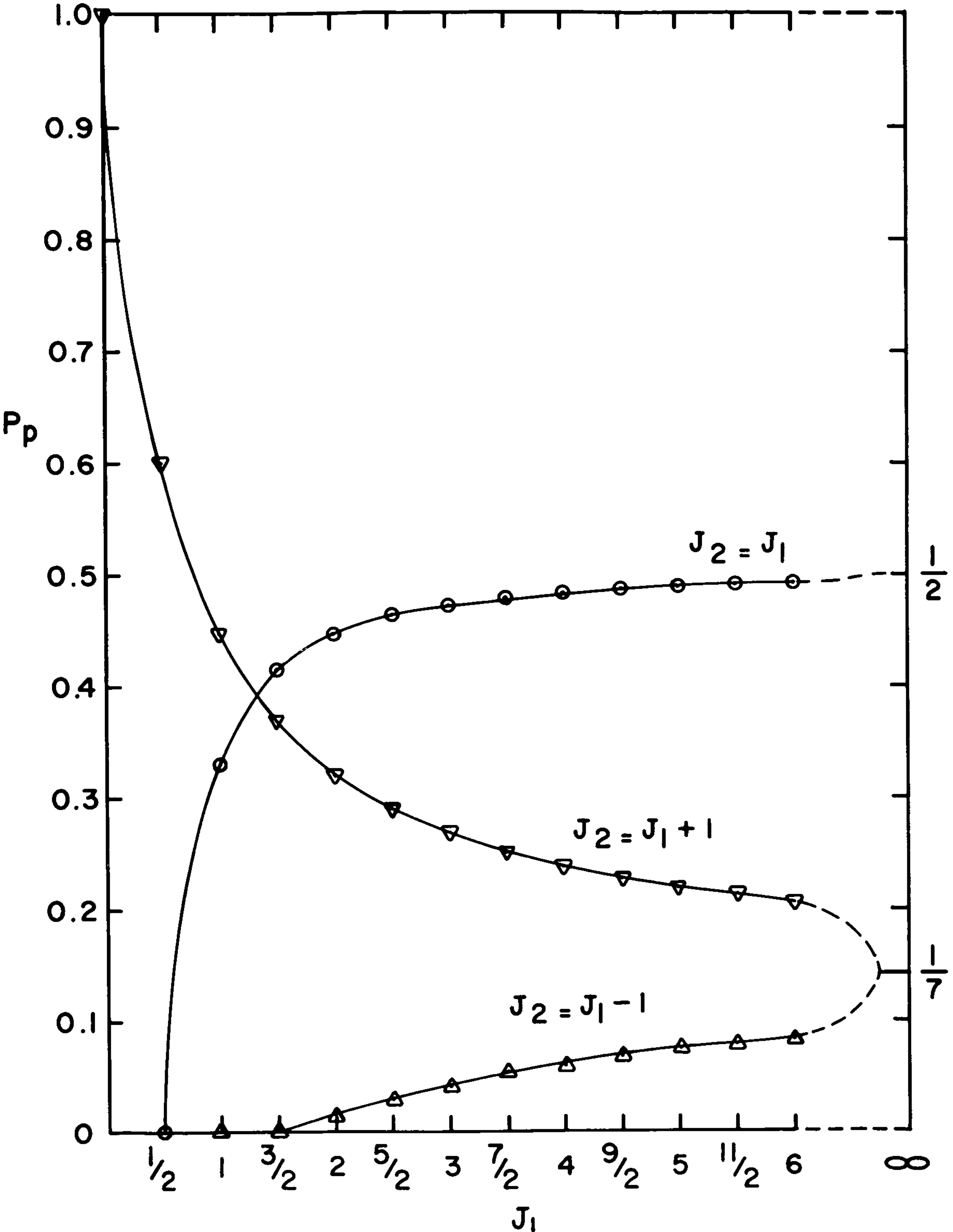

Figure 1–Polarization produced by single resonance scattering of linearly polarized light for $\Delta J = 0, \pm 1$ versus the ground state J_1.

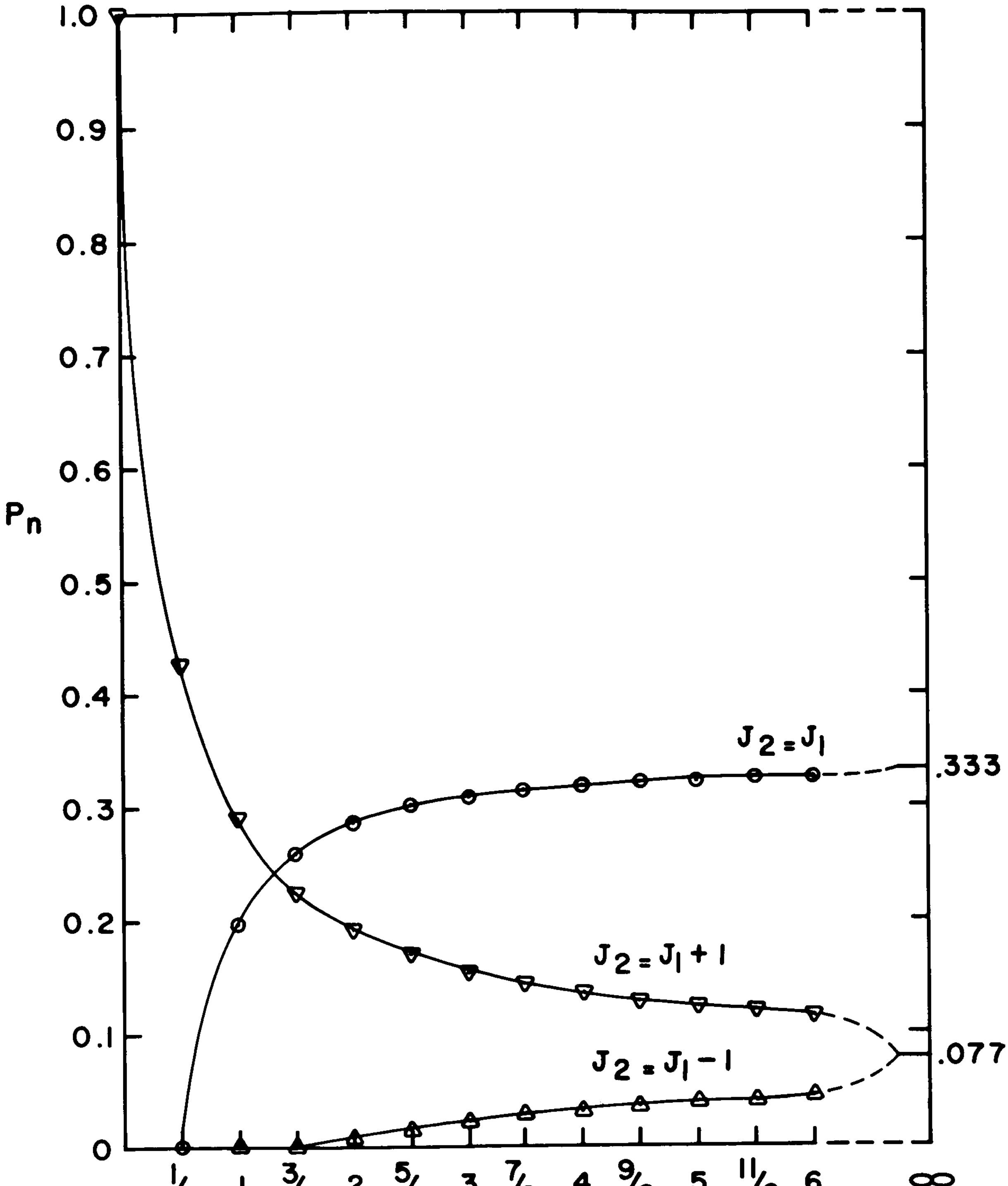

Figure 2—Polarization produced by single resonance scattering of unpolarized (natural) light for $\Delta J = 0, \pm 1$ versus the ground state J_1.

Figure 3—For ultraviolet polarization analyzer with the transmission pile-of-plates analyzer (top and rear aperture removed) and filter wheel alongside.

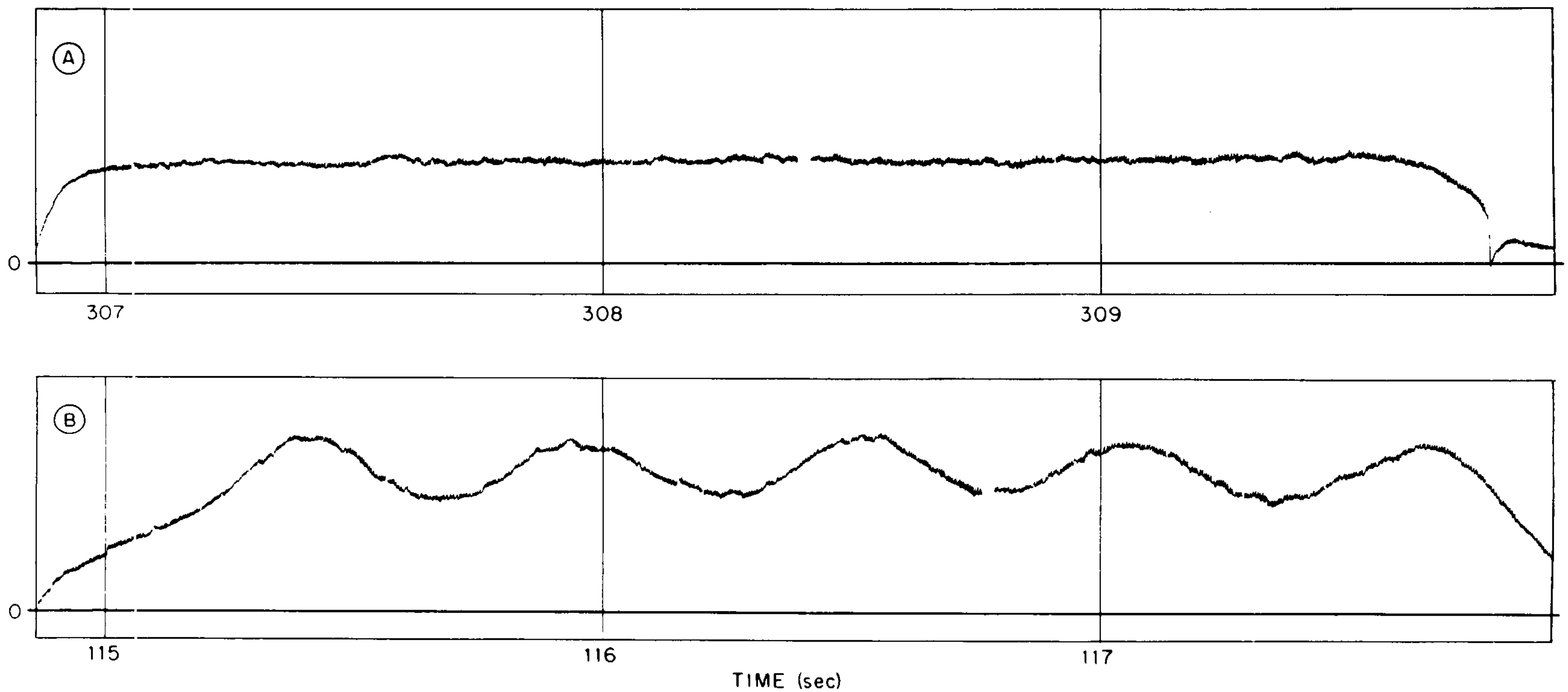

Figure 4–(A) Telemetry record showing absence of observable polarization of Lyman – α (B) Polarization resulting from scattering of direct sunlight off the photometer baffle.

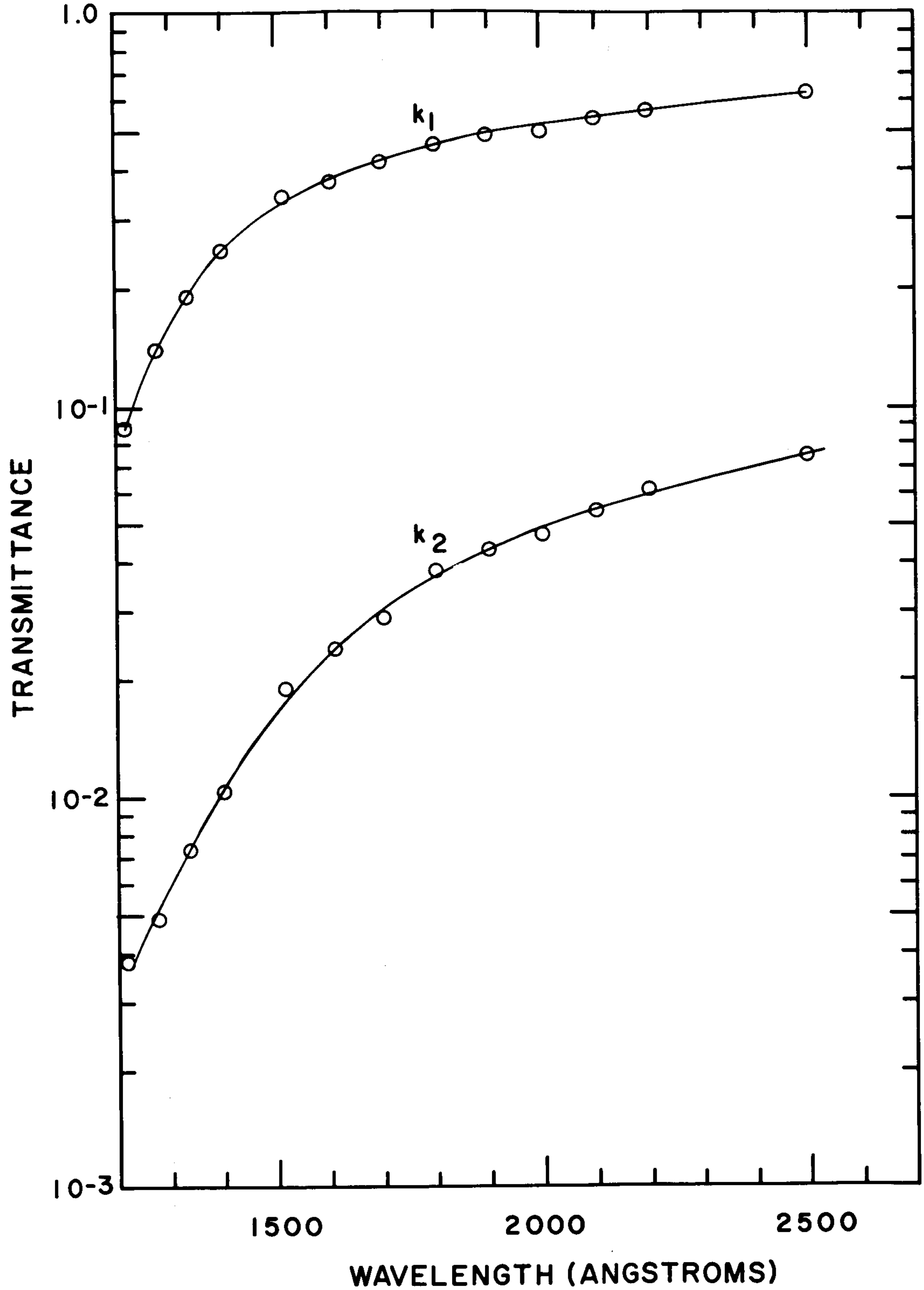

Figure 5—Major, k_1, and minor, k_2, principal transmittances of polarization analyzer.

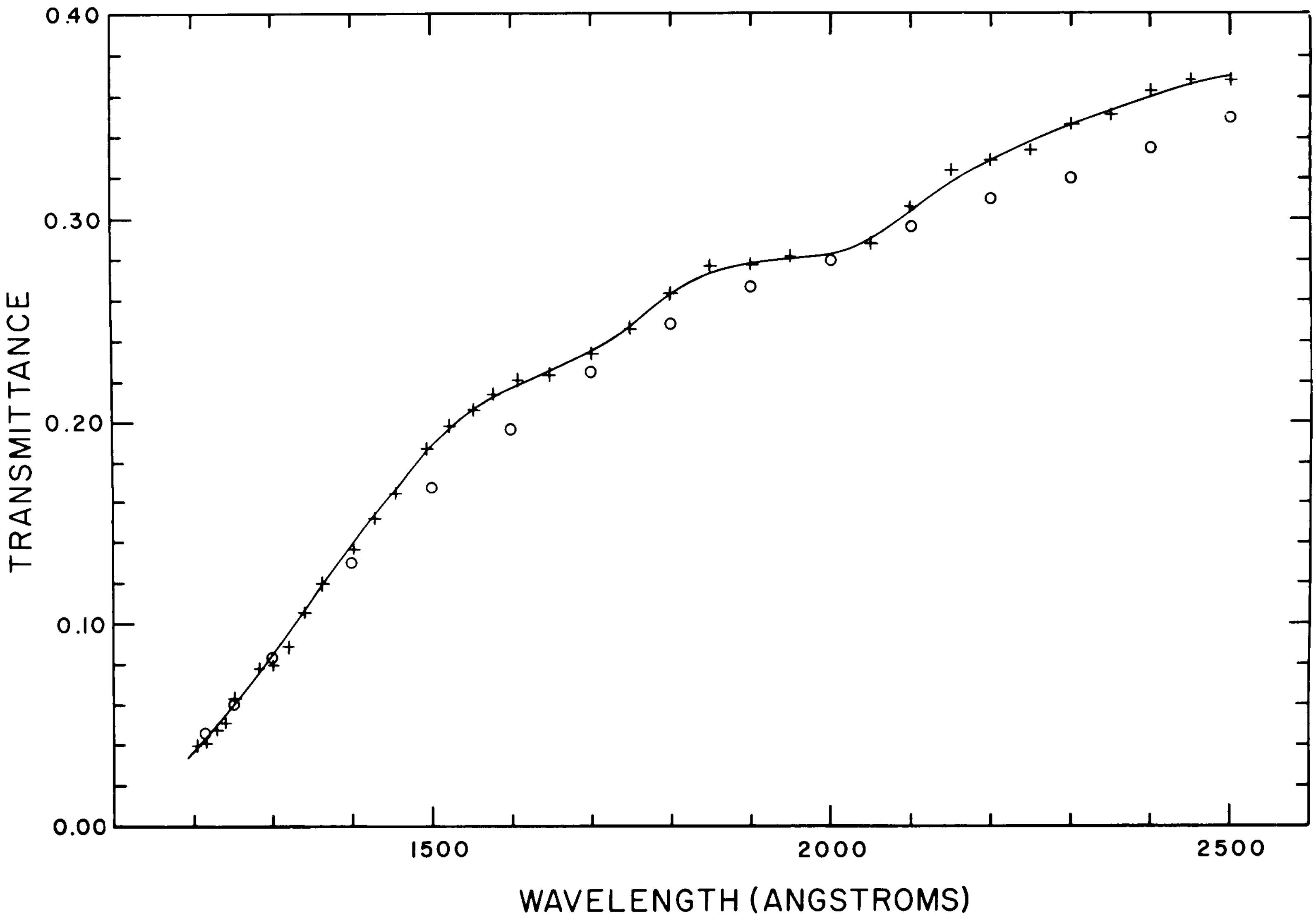

Figure 6—Measured transmittance for unpolarized radiation is shown by crosses and the solid curve. The calculated transmittance, $T = 1/2\ (k_1 + k_2)$ is given by open circles.

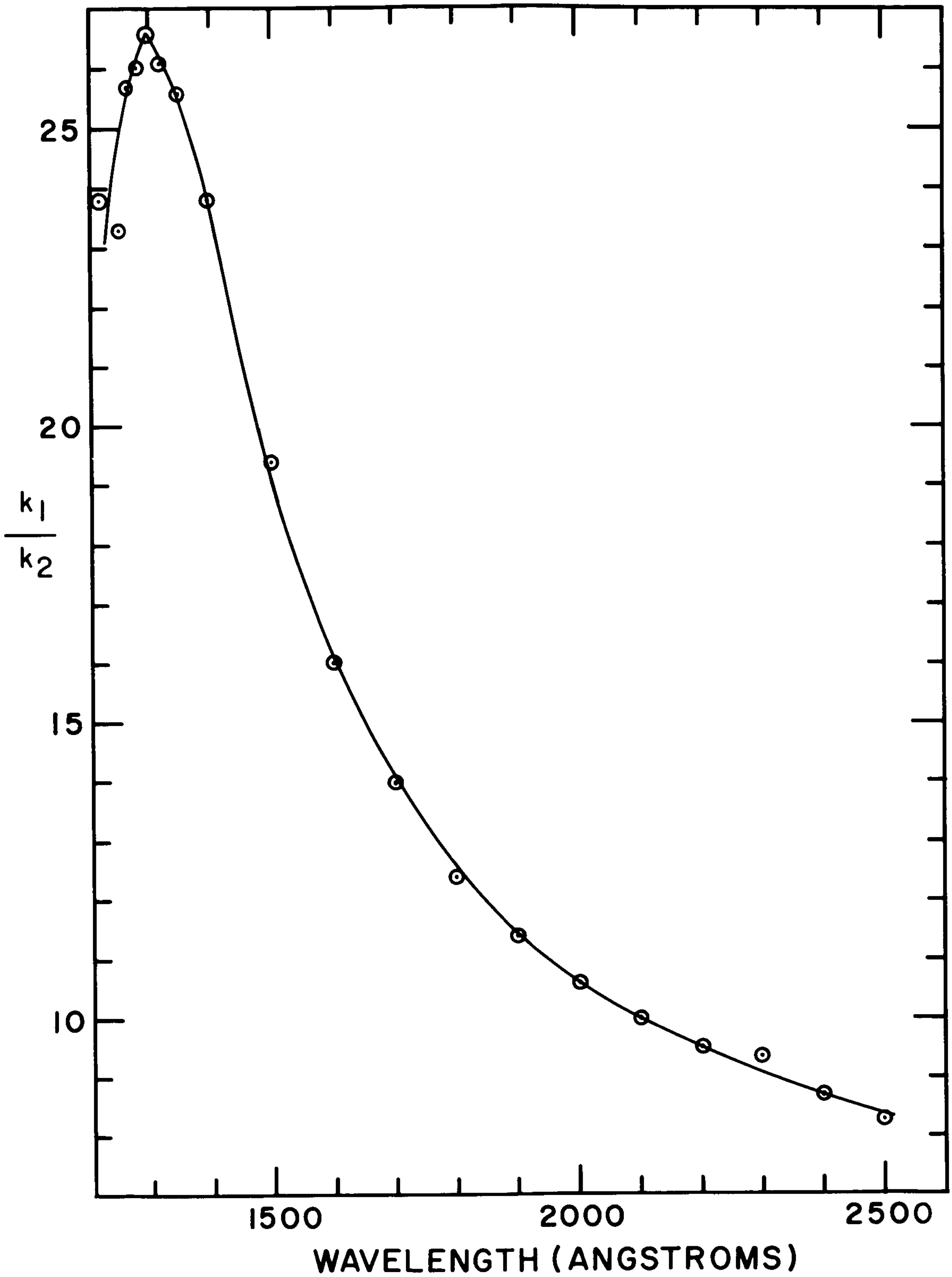

Figure 7—Ratio of major, k_1, to minor, k_2, principal transmittances.

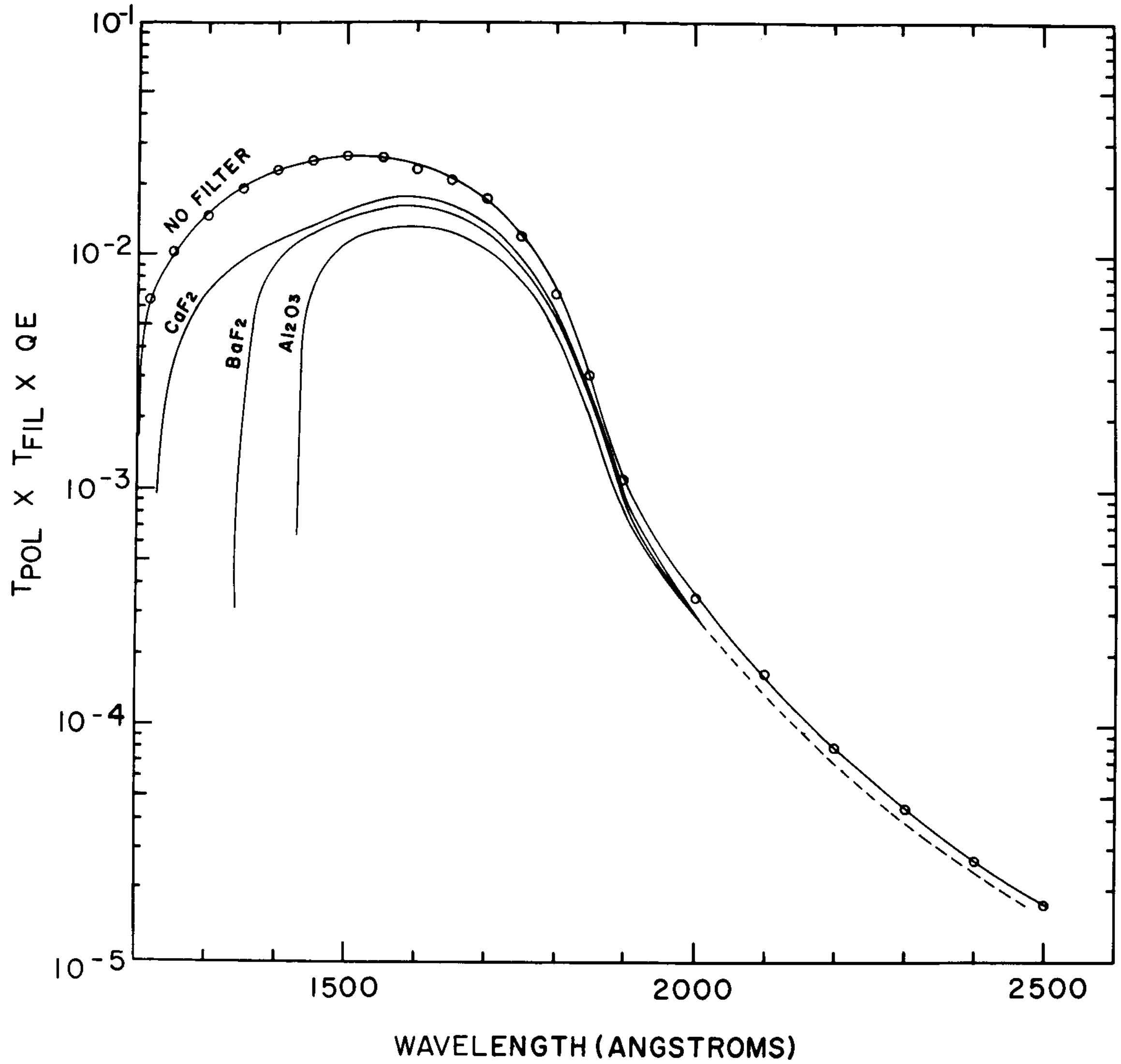

Figure 8—Product of transmittance of polarization analyzer, transmittance of filter, and quantum efficiency of ASCOP 542G.

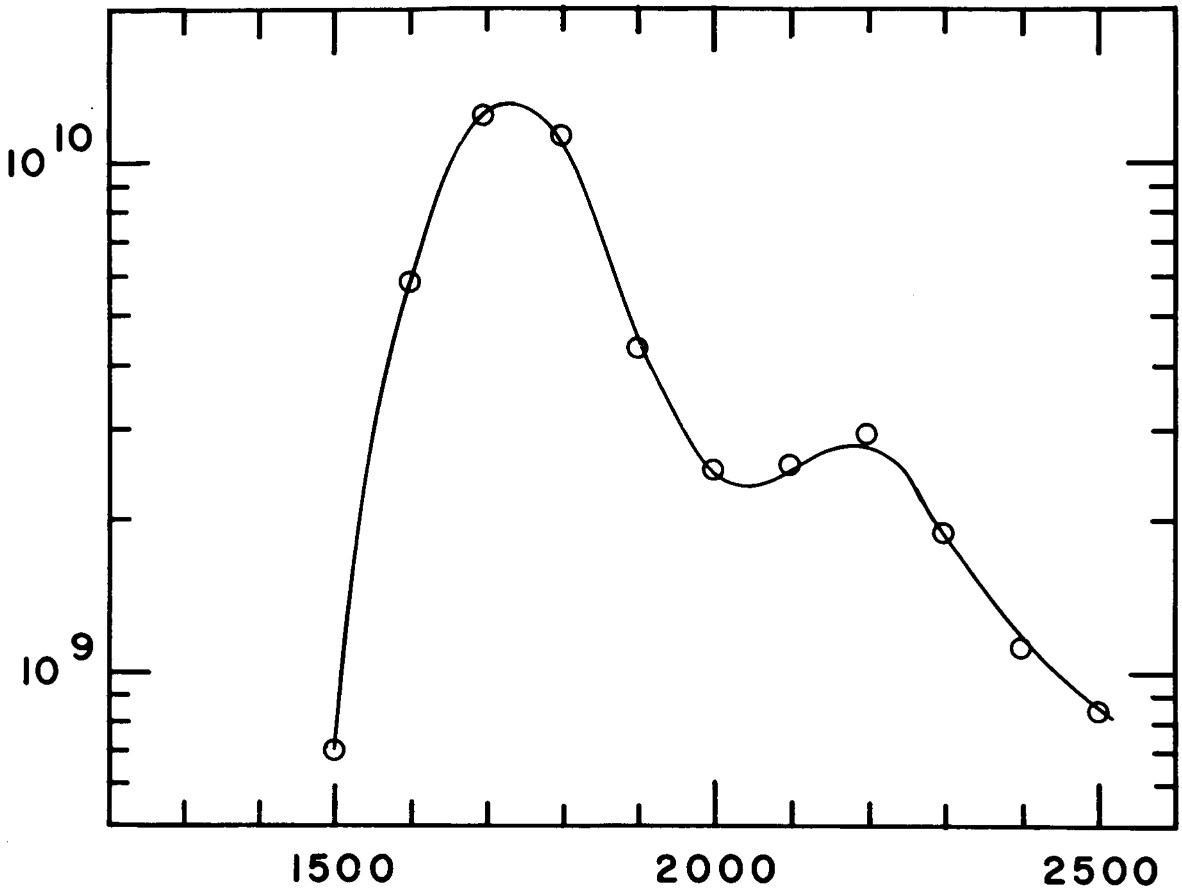

Figure 9–Relative sensitivity of polarization analyzer to scattered solar radiation (product of transmittance of analyzer, quantum efficiency of photomultiplier, and solar flux) assuming that the coefficient for scattering off the blackened baffle is independent of wavelength.