of glazed sherds. No dates were obtained from the El Abra rock-shelters indicative of the introduction of maize and ceramics. Possibly the introduction occurred about A.D. 300 if the charred maize grains associated with Chibcha types of pottery at the Los Solares, Sogamosa, site by E. Silva Celis are representative of the initial entrance into the sabana of these traits. His maize sample (sample GrN-4729) is dated 1640 ± 50 B.P. (A.D. 310).

The pollen profile of unit E reveals a decrease in the areas of forests accompanied by an increase in the vegetation of open areas. This fact may be the result of increasing deforestation of the sabana by man for agricultural purposes. The caves were still used by small groups of men at uneven intervals even though there was a slight increase in the estimated annual deposition of chert (2.6 pieces in contrast to 0.36 piece in the underlying subunit D2).

Because so few other preceramic sites in Colombia have been excavated, it is not possible to make detailed comparisons. Those tools that we have examined and additional ones briefly noted by Reichel-Dolmatoff (*4*) differ from the ones from El Abra in that they exhibit more elaborate methods of manufacture and a greater variety of types, such as large choppers, bifaced tools, or stone projectile points.

The Chibcha cultures continued to make crude chert tool types, but a great variety of new artifacts and methods of manufacture were added. Thus, in the uppermost levels of the El Abra rock-shelters are sherds, ground stone celts, ground slate knives, stone mortars, and bronze poncho pins.

WESLEY R. HURT
Indiana University Museum,
Bloomington 47401

THOMAS VAN DER HAMMEN
Hugo de Vries-Laboratorium,
Universiteit van Amsterdam,
Amsterdam 4, Netherlands

GONZALO CORREAL URREGO
Instituto Colombiano de Antropologia,
Apartado Nacional 407,
Bogotá, Colombia

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Frequencies of Occultations of Stars by Planets, Satellites, and Asteroids

Abstract. *Calculations show that several occultations of stars by the large satellites of the outer planets, Pluto, and the large asteroids could be observed each decade with existing equipment at Earth-based telescopes. A systematic program of occultation predictions and observations is urged in order to improve our knowledge about the atmospheres, sizes, shapes, topography, and positions of these poorly understood bodies, in support of forthcoming spacecraft missions to the outer solar system.*

Every once in a while a planet passes in front of a star of comparable brightness. These occultation phenomena, though infrequent, arouse a great deal of interest among astronomers. From photoelectric light curves it is possible, in principle, to probe a planet's upper atmosphere in detail to obtain significant clues as to its temperature and composition (*1*); to detect the presence or lack of a very thin atmosphere; and to determine the diameter, shape, topography, and position of the planet with great accuracy. The recent occultation of Beta Scorpii C by Jupiter's satellite Io is a case in point. The upper limit to the pressure of Io's atmosphere has been lowered by several orders of magnitude to about 10^{-4} mb, and the precision in measuring Io's diameter, now known to within a few kilometers, has been improved by nearly two orders of magnitude (*2*).

The occultations that have been predicted and successfully observed in modern times are listed in Table 1 (*2–5*). From the shortness of the list we see that, for a given planet, these events are rare indeed. The question is, just how rare are they? Meeus (*6*) considered planetary occultations of the five brightest stars in the zodiac. His outlook was bleak: one occultation of Regulus by Venus and Mercury every 500 to 600 years, one occultation of Spica by Venus every 2000 years, and essentially no others.

No study has yet been made for fainter stars. In this report a recipe is provided for predicting the frequency of observable occultations of stars by all bodies of appreciable size in the solar system, other than the sun and the moon. This census includes those objects whose mean angular diameters exceed about 0.1 arc second, that is, the eight other planets, fourteen satellites of the outer planets, and the four asteroids for which accurate ephemerides are known.

These calculations are subject to a number of assumptions, and the final answers are not rigorously accurate. Nevertheless, they indicate the objects that are most susceptible to occultations and, therefore, the direction that prediction and experimentation ought to take. The frequencies are computed, first, by determining the area of the sky swept out by each object each year. Two general cases are considered: occultations observable in the night sky above a given site on the earth and occultations observable from somewhere on the earth. As seen from a given site, the area swept out is the product of the occulting object's mean angular motion and its mean angular diameter; as seen from some region on the earth—and it is just as likely to be New Guinea as Mt. Palomar—the area is the product of the object's mean angular motion and the sum of its angular diameter and twice its geocentric parallax. The mean motion and mean parallax for each planet are listed in Table 2. Once the area has been determined, one simply multiplies this by the mean number of eligible stars per unit area that are brighter than the appropriate magnitude (*7*) to obtain the frequency of occultations.

The calculations are subject to the following assumptions.

1) The near ultraviolet (about 3600 Å) is the best region for observing occultations. This is because most bodies in the solar system resemble late-type stars in having very red color indices. Thus, in most cases, observing in the ultraviolet minimizes the brightness of the planet with respect to that of the occulted star.

2) Counts of stars in a given magnitude range per square degree of sky are taken for photographic (blue) magnitude (*7*). Transforming these counts to the ultraviolet requires an adjustment in the ultraviolet − blue ($U - B$) color index which is negligible for most stars, that is, those bluer than spectral type K0 and redder than A0 (*7*). This transformation has been neglected.

3) Star counts correspond to those at intermediate galactic latitudes, that is, the "mean" values compiled by Allen (*7*). Table 2 includes a list of the galactic latitudes of the outer planets on 1 January 1972 (the other planets move fast enough to yield a "mean" result during the course of a year or two). With the exception of Jupiter and Pluto, the outer planets are situated at intermediate galactic latitudes. Averaged over the next several decades, these star counts should be well within a factor of 2 of the mean values.

4) The mean angular motion of a planet in the sky is obtained from its movement in right ascension and declination, given in the *American Ephemeris and Nautical Almanac* (*8*), over a representative time span of 1 or 2 years (Table 2). Each satellite has an added motion that is sometimes an appreciable fraction of that of its parent planet—in the case of Io, almost 50 percent. On the other hand, the satellite moves fastest while it is in conjunction with the planet, and these are the times when it is poorly visible or not visible at all. We assume that these effects roughly cancel out and that each satellite's motion in the sky during periods of observation is the same as that of its planet.

5) Mean apparent diameters and mean geocentric parallaxes are assumed; time-variant deviations are greatest for the closest planets and are negligible for distant objects.

6) It is assumed that one out of five occultations in line with a given site will be observable in the night sky over that site. This takes into consideration a factor of 2 because only one hemisphere can be seen, another factor of 2 because observations can only be made at night, and another 20 percent for poor observing conditions, that is, twilight and low altitude. The last effect is considerably greater for Mercury and Venus, for which observations are almost always made in a bright sky. On the other hand, very bright stars can be observed in the daytime, as in the case of the occultation of Regulus by Venus. The factor of 5 is still adopted for Mercury and Venus.

The results are shown in Table 3. In comparing observations from a given site on the earth with observations from somewhere on the earth, we see that occultations can be seen much more frequently when one is willing to mount an expedition to perform the observations. This gain is especially dramatic for objects smaller than the earth; then the baseline provided by geocentric parallax "buys" the observer more space to move into the object's cylindrical shadow of the star.

Two subcases are considered: "good" occultations, in which the intensity change in the ultraviolet light curve is 50 percent or greater (that is, the star is at least as bright as the planet in *U* magnitude), and "passable" occultations, in which the intensity drop is 10 percent or greater (that is, the star is, at most, 2.5 magnitudes fainter than the planet in *U*).

Any drop of less than 10 percent in intensity is assumed to be a marginal observation because of signal-to-noise problems in the photometry; it is especially difficult to interpret in the case of a planet with an atmosphere, for which the intensity changes gradually during immersion and emersion. There are possible ways around the signal-to-noise problem for brighter objects seen through telescopes with large apertures. In observing the occultation of Sigma Arietis by Jupiter, Baum and Code (*3*) used a spectral band-pass of 10 Å centered in the *K* line of ionized calcium. Because the star totally lacked this absorption, which cuts out most of the reflected sunlight from Jupiter, it was possible to gain a factor of about 4 in the intensity ratio of star to planet. Moreover, Venus, Mars, Jupiter, and Saturn at most times have large enough angular diameters to isolate only the region of occultation at the planet's limb, so that a greater contribution by the star is gained. Bearing in mind these considerations, I have estimated the photographic magnitudes of the faintest stars for which reasonable occultation measurements can be performed (Table 3, column 9). For the four brightest planets, a candidate star can be eligible for occultation measurements even if it is considerably less than one-tenth as bright as the planet.

In the last column of Table 3 I have listed the telescope apertures necessary to produce 100 counts per second for observations made through a wide-band *U* filter with a photomultiplier with high quantum efficiency. This arrangement corresponds to 10 percent r.m.s. fluctuations in the photon statistics for the planet for 1-second integration times, a time resolution that normally translates into resolutions on the planet of about 10 km (or one scale height). These figures are conservatively estimated from theoretical considerations and from the direct experience of observing Pluto at the Mt. Palomar 200-inch telescope (1 inch = 2.54 cm). In effect, these apertures are considered the minimum values necessary for getting meaningful results from occultations; they can serve as a rough guide in deciding whether a given occultation should be observed with a given apparatus, at home or in the field. A practical lower limit of 3 inches in aperture was set because at smaller apertures there are serious problems with scintillation noise. We

Table 1. Recent occultations of stars by planets and satellites.

Date (U.T.)	Planet and star	Visual magnitude of planet	Visual magnitude of star	Reference
20 November 1952	Jupiter and Sigma Arietis	−2.4	5.5	(*3*)
7 July 1959	Venus and Regulus	−4.2	1.3	(*4*)
7 April 1968	Neptune and BD −17° 4388	7.7	7.8	(*5*)
13 May 1971	Jupiter and Beta Scorpii A and B	−2.3	2.6	(*2*)
13 May 1971	Jupiter and Beta Scorpii C	−2.3	4.9	(*2*)
14 May 1971	Io and Beta Scorpii C	5.0	4.9	(*2*)

Table 2. Preliminary data for calculation of stellar occultation frequencies for each planet. The mean geocentric parallax is expressed in earth diameters. The galactic latitude is for 1 January 1972.

Planet	Mean motion (deg/year)	Mean geocentric parallax (arc seconds)	Galactic latitude (deg)
Mercury	450	18	
Venus	250	18	
Mars	200	15	
Asteroids	130	6	
Jupiter	50	3.5	12
Saturn	28	2.0	29
Uranus	12.5	1.1	55
Neptune	8.2	0.6	25
Pluto	7.8	0.6	68

see that small-aperture telescopes (about 20 inches) are adequate for observations of all objects except Pluto and the satellites of Uranus and Neptune.

The occultation frequencies in columns 4, 5, 7, and 8 of Table 3 are given per decade, which is a convenient time scale for a systematic research program. With the possible exception of the frequencies for the brightest planets, Pluto, and the faintest satellites, these figures should be correct within a factor of 2 when integrated over several decades. In order to minimize confusion in the interpretation of Table 3, we pay particular attention to the "passable" occultations, those that involve an intensity drop of greater than 10 percent, and allow ourselves the freedom of pursuing a given occultation at a suitable field station (column 8). The results are quite interesting and are discussed in the following paragraphs.

Observable occultations are very infrequent for the planets but generally increase the farther out one goes in the solar system. The estimates given in Table 3 for Venus, Mars, Jupiter, and Saturn are quite unrealistic, since it is possible to decrease the magnitude gap between star and planet with K-line photometry and with areal resolution on the disk. More reasonable values, given in parentheses, are based on the number of candidate stars that are brighter than the faintest estimated magnitude listed in column 9 of Table 3. Pluto is by far the best candidate; at least one "passable" event per year can be observed from somewhere on the earth. In recent years there have been two near misses of occultations of Pluto with stars of comparable magnitude, as seen from the southwestern United States (*9*). The first event could almost certainly have been seen from

Table 3. Frequencies of occultations of stars by planets, satellites, and asteroids. In columns 4, 5, 7, and 8, N is the number of stars occulted in 10 years. The factor of 5 takes into account that one out of every four occultations will be visible in the night sky above a given site and that an additional 20 percent of occultations will be invisible because of poor conditions, that is, low altitude and twilight. "Good" occultations involve at least a 50 percent drop of intensity in U magnitude; "passable" ones involve at least a 10 percent intensity drop. In column 6, the larger area swept out is due to the geocentric parallax of the object (see Table 1). The minimum telescope aperture is the approximate aperture, based on the mean U magnitude of the planet, that will produce 100 photon counts per second for observations through a wide-band U filter with a phototube of high quantum efficiency. The aperture is given in inches (1 inch = 2.54 cm).

			Observable from a given site			Observable from somewhere on the earth				
	1 U magnitude (mean)	2 Mean diameter (arc seconds)	3 Area swept in sky (deg^2/year)	4 "Good" occultations $N/5$	5 "Passable" occultations $N/5$	6 Area swept in sky (deg^2/year)	7 "Good" occultations N	8 "Passable" occultations N	9 Faintest photographic magnitude of occulted star	10 Minimum telescope aperture (inches)
					Planet					
Mercury	+1.9	7	0.9	0.0009	0.02	3.1	0.015	0.25	5	3
Venus	−2.3	15	1.0	0	0.0001 (0.005)‡	2.3	0	0.001 (0.05)‡	5	3
Mars	+1.9	9	0.5	0.0005	0.01 (0.02)‡	1.3	0.006	0.14 (0.3)‡	7	3
Jupiter*	−0.8	37	0.47	0.00003	0.001 (0.02)‡	0.51	0.00015	0.005 (0.1)‡	7	3
Saturn	+2.6	17	0.13	0.0003	0.005 (0.01)‡	0.15	0.0015	0.03 (0.08)‡	8	3
Uranus	+6.5	3.8	0.013	0.003	0.04	0.017	0.02	0.3	9	3
Neptune	+8.5	2.4	0.0055	0.010	0.10	0.0068	0.06	0.6	11	3
Pluto†	+16.0	~0.15	~0.0003	~0.6	~5	0.002	~20	~150	18	70
					Satellite					
Ganymede*	+6.3	1.4	0.019	0.004	0.04	0.065	0.06	0.7	9	3
Europa*	+7.0	0.8	0.011	0.004	0.05	0.057	0.10	1.4	10	3
Callisto*	+7.3	1.2	0.016	0.009	0.10	0.063	0.18	1.9	10	3
Io*	+7.7	0.9	0.012	0.01	0.13	0.059	0.24	3.0	10	3
Titan	+10.8	0.75	0.0058	0.10	1.2	0.021	2.0	22	13	7
Rhea	+11.2	0.20	0.0015	0.04	0.4	0.017	2.4	24	14	9
Tethys	+11.7	0.15	0.0012	0.05	0.4	0.017	3.9	29	14	11
Dione	+11.8	0.13	0.001	0.05	0.4	0.017	4.2	31	14	11
Iapetus	+12.4	~0.1	~0.0008	~0.07	~0.6	~0.016	~7	~50	15	15
Enceladus	+13	~0.1	~0.0008	~0.1	~0.9	~0.016	~12	~90	15	20
Mimas	+13	~0.1	~0.0008	~0.1	~0.9	~0.016	~12	~90	15	20
Titania	+15	~0.1	~0.0003	~0.2	~2	~0.004	~12	~130	17	50
Oberon	+15	~0.1	~0.0003	~0.2	~2	~0.004	~12	~130	17	50
Triton	+15	~0.15	~0.0003	~0.3	~3	~0.0025	~8	~80	17	50
					Asteroid					
Ceres	+8.5	0.3	0.011	0.02	0.2	0.2	2	20	11	3
Pallas	+9.7	0.2	0.007	0.04	0.6	0.2	6	80	12	5
Vesta	+8.1	0.2	0.007	0.008	0.1	0.2	1	14	11	3
Juno§	+10.8	0.1	0.004	0.07	0.8	0.2	17	200	13	7

* These frequencies should be doubled for the next 2 years, because of Jupiter's location near the galactic center. † These frequencies are overestimates by a factor of 3 for the next several decades because of Pluto's location at high galactic latitudes. ‡ Estimated number of observable occultations in which the region of occultation can be isolated from the rest of the planet. These frequencies are more realistic and are based on the mean number of stars brighter than the magnitudes listed in column 9. § And several others.

South America, had observers there been informed about it in time.

Next in frequency are Neptune and Uranus; on the average, there should be one observable event each decade. Neptune's present location at low galactic latitudes should help increase the probability somewhat. Even so, an event like the 1968 occultation of a star brighter than eighth magnitude (*5*) would occur only once in a century (Table 3, column 7). Finally, the five bright planets should present observable occultations only about once in a century. Events such as the occultation of Regulus by Venus and the occultations of Sigma Arietis and Beta Scorpii by Jupiter should be even less frequent. Although these samples are too few for reliable statistics, it is apparent that in the last two decades a fortuitously high number of occultations occurred between bright stars and bright planets (*6*).

For the satellites it is a much different story, and this is where most of the potential excitement lies. Although the occultation of Beta Scorpii by Io was a fortuitous one (Io should occult a star this bright once every 1000 years), observable encounters with fainter stars are relatively frequent. It is possible that by the end of the decade occultations involving all four of Jupiter's Galilean satellites will be observed. With proper planning, we should have answers to questions about thin atmospheres on the Galilean satellites as well as detailed information about their diameters, shapes, and positions (see note added in proof).

The situation with Saturn's satellites is even more promising. Two or more events occur each year for each of the seven largest satellites, but a moderate-aperture telescope is required to observe most of these events, which involve thirteenth to fifteenth magnitude stars. From a given observatory, on the average, one "passable" event could be observed each decade for each satellite (Table 3, column 5). Since we know that Titan has an atmosphere, it is obviously of interest to probe it by occultation techniques, and the statistics predict frequent enough events for this satellite.

The two largest satellites of Uranus and Neptune's satellite Triton are even better candidates; their predicted occultation frequencies are similar to those of Pluto. (Unfortunately, Triton is difficult to observe because its separation from Neptune never exceeds 20 arc seconds.) High occultation frequencies also apply to the larger asteroids. Thus, we see that the large satellites of the outer planets, Pluto, and the large asteroids—objects whose sizes range from a few hundred to a few thousand kilometers—are prime candidates for observations of stellar occultations. In principle, a systematic attack on the problem should yield information about the physical properties and positions of these poorly understood objects, prior to and concurrent with spacecraft missions to the outer solar system.

The problem remains of the mechanism and accuracy of prediction. Occultations of stars brighter than ninth magnitude by the seven brightest planets and the four largest asteroids are predicted by G. E. Taylor. These predictions are based on a combination of planetary ephemerides with a magnetic-tape version of the *Smithsonian Astrophysical Observatory Star Catalogue* (*10*). The program is now being extended to include the Galilean satellites. On the other hand, column 8 of Table 3 tells us that the most frequent events occur with far fainter objects, Pluto and the satellites of Saturn, Uranus, and Neptune. Predictions for these must be performed by photographing the sky ahead of the planet in question and measuring the plates immediately; this method has already been applied to Saturn's rings with stars down to twelfth magnitude and to Pluto with stars down to seventeenth magnitude (*11*). The need for continuous monitoring of the sky ahead of Saturn, Uranus, Neptune, and Pluto, in relation to stars brighter than the photographic magnitudes listed in column 9 of Table 3, is apparent.

A major source of inaccuracy in the predictions are errors in star positions and in the ephemerides of the planets or satellites. These errors are typically a few tenths of an arc second in the direction perpendicular to motion, and in certain instances, as in the 1968 occultation by Neptune, they can exceed 1 arc second (*5*). Satellites whose angular diameters are of the order of 0.1 arc second would seem hardly worth mounting an expedition for. However, there are ways to refine the predictions, but it is not within the scope of this report to discuss them (*12*). The Galilean satellites and Titan, with angular diameters of the order of 1 arc second, are relatively immune from this problem.

Taylor (*9*) predicts about 23 occultations by Mars, 16 by Jupiter, 2 by Saturn, 1 by Uranus, and 2 by Neptune of stars brighter than ninth visual magnitude between 1972 and 1980. If these predictions are converted in terms of the photographic magnitudes listed in column 9 of Table 3, Taylor's frequencies correspond closely to those calculated in this report. It is interesting to note that Jupiter will be at very low galactic latitudes over the next 2 years and will actually pass within a few degrees of the galactic center, so that the occultation frequencies given in Table 3 for Jupiter and the Galilean satellites should be doubled for 1972 and 1973.

In conclusion, I urge that a systematic and expanded system of occultation predictions be initiated to include stars as faint as those listed in column 9 of Table 3 for each of the planets, satellites, and asteroids considered. In view of the short lead times (of the order of a few weeks) for the fainter and more frequent events, there should be a system of cooperation among observatories, whose staffs should be on the lookout for predictions in International Astronomical Union circulars and equipped to observe each event. The more observations there are of an event, the better is the probability of success. Moreover, an object's diameter can be obtained only if there exist two or more chords across the disk, as observed from different sites on earth in timing the event. The full potential of this undertaking can be realized only through cooperation and not through competition (*13*).

Note added in proof: G. E. Taylor, of the Royal Greenwich Observatory, has recently sent me some preliminary predictions of three occulations of eighth magnitude G and K stars by Ganymede, two of which might be observed from points in South Africa in June 1972. Efforts are under way to observe these events. Of the Galilean satellites of Jupiter, Ganymede has the largest escape velocity and thus the highest probability of retaining an atmosphere. Although the predicted intensity drops for these events are somewhat less than 10 percent, they should be sufficient to answer the main questions, given careful preparation.

BRIAN O'LEARY*
Division of Geological and Planetary Sciences and *Jet Propulsion Laboratory, California Institute of Technology, Pasadena 91109*

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10. These predictions are published in the handbook of the British Astronomical Association, and a copy is sent to the Royal Astronomical Society of Canada. Important events are also announced in circulars put out by the International Astronomical Union. An outline of predictions for the next 9 years was written by G. E. Taylor for presentation at the meeting of the American Astronomical Society, Division for Planetary Sciences, in Tallahassee, Florida, February 1971, and is available upon request from the Royal Greenwich Observatory, Greenwich, England. T. Van Flandern of the U.S. Naval Observatory has advised me that the AGK 3 star catalog [*Astronomische Gesellschaft Katalog* (Engelmann, Bonn, Germany), vol. 3] is also on magnetic tape and could be used to predict occultations of stars north of −2° declination, down to magnitude 10.5. Such a program would be useful as a check to the existing program based on the star catalog of the Smithsonian Astrophysical Observatory and would allow a much larger popuation of stars to be applied to prediction of occultations by the Galilean satellites, Titan, Neptune, and the asteroids.
11. This work is being carried out by G. E. Taylor upon special request by individual scientists.
12. Studies are under way to find methods of sharpening predictions once the initial announcement is made. For example, star positions can be remeasured on plates, and residuals from the ephemerides for the planet or satellite, or both, can be studied. With 2 weeks notice, it was possible to improve the accuracy of observation of the occultation of Beta Scorpii C by Io to about 0.2 arc second in the direction perpendicular to the motion of the satellite.
13. I quote a reviewer of this paper about the need for cooperation: "If predictions are to be extended in some cases to objects as faint as magnitude 17 or 18, this cooperation will have to extend to those astronomers with suitable astrometric instruments and skills. It is certainly true that predictions in the past have been hampered by inadequate astrometry, coupled with the use of ephemerides that are not as good as they should be (e.g. the Pluto miss in March 1971). Satisfactory ephemerides for all the major and large minor planets can and should be supplied; the satellites are more of a problem, but given time this can be solved too (and fortunately, as the author points out, in some cases one has the advantage of size)."

14. I thank Drs. T. Van Flandern, G. E. Taylor, and R. Brinkmann for helpful discussions and correspondences.

* Presently at the Department of Interdisciplinary Sciences, San Francisco State College, California, and National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California.

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Raman Scattering from Flames

Abstract. *Laser Raman scattering data for nitrogen, oxygen, and water vapor have been obtained from hydrogen-air and hydrogen-oxygen flames. The resulting ground-state and upper-state vibrational bands exhibit strong asymmetrical broadening. Experimental spectral profiles have been fitted theoretically to give a new measurement technique for the determination of rotational and vibrational excitation temperatures.*

We report here observations of vibrational Raman scattering from flame gases. One motivation for these observations is that Raman scattering can provide spatially resolved measurements of the concentration and the vibrational and rotational excitation temperatures of flame constituents. This capability should prove to be of substantial use in the diagnostics of nonequilibrium as well as equilibrium phenomena.

The work presented here is focused upon the observation of temperature-dependent effects in the spectral distribution of the Stokes Q-branch vibrational scattering. These effects arise predominantly from the vibration-rotation interaction and from significant populations of excited vibrational levels. From these excited levels originate upper-state bands (*1*) which are usually shifted toward the blue region of the spectrum.

In Fig. 1 we show the types of fundamental vibrational Raman scattering events that may be observed in flames. Earlier Raman scattering experiments at elevated temperatures have dealt with laser heating of a vapor (*2*), with studies of species in ovens at temperatures up to 1000°C (*3*), and with a low-pressure electric discharge (*4*). We have been unable to find any earlier publications concerning Raman scattering in flames or in any systems at temperatures in excess of 1000°C.

Our initial observations were confined to Stokes bands arising from 4880-Å incident radiation from an argon ion laser (Coherent Radiation model 52B) operated for most data at 1.5 watts. The scattered light was analyzed by a double monochromator (Spex 1400-II) with 5000-Å blazed gratings. The detector was a cooled photomultiplier (RCA C31000E Quantacon) operated in the pulse-counting mode with dark current levels of about 18 counts per second for this work.

The overall experimental arrangement was designed to have the laser beam traveling along the direction of the entrance slits (that is, vertically) and focused at a position about 0.3 m from the entrance slits. The Raman-scattered radiation was collected by a multielement lens with a focal length of 75 mm. The width of the laser beam in the scattering zone was about 100 μm, and the height from which the scattered radiation was accepted (as determined by the 1-cm slit height and the image magnification factor of 2) was about 5 mm. The monochromator entrance and exit slits were set to 300 μm, for which the spectral slit width was measured to be in very close agreement with the value calculated from the instrument dispersion curve. The (Rayleigh and Mie scattering) image of the laser beam at the entrance slits (as viewed by a periscope attachment behind the slits) showed no change when the flame was ignited.

The flames studied were produced on a water-cooled porous plug burner (diameter, 2.5 cm) (*5*) operated horizontally and burned into another water-cooled porous plug (of larger diameter) placed about 1.5 cm away which was, in turn, connected to a rough vacuum line. In this fashion, a stable horizontal flame at atmospheric pressure was produced which possessed the advantage of offering a scattering test zone of uniform conditions (that is, at a constant distance from the flat flame front) for a laser beam passing in the vertical direction. Scattering data for H_2O and O_2 were obtained from lean H_2-O_2 flames, whereas data for N_2 was obtained from a lean H_2-air flame. Because of the low luminosity of these flames in the spectral regions of interest, no increase in background was observed when the flames were ignited. Precise flow data were not taken, nor