This is consistent with the observations of three subjects exposed to individual nitorgen ions at the Princeton Particle Accelerator (*3*). Broken streaks have been observed in space and in laboratory experiments (*5*). It is possible that fragmentation of the carbon nucleus and interactions that lead to the formation of nuclear stars play a role in these effects, but further study is needed.

Table 2 shows the data for subjects P.M. and V.P. and for pulses containing one or more particles. Their ability to detect pulses containing one particle was not significantly different from their ability to detect pulses containing more than one particle—that is, the detection efficiency per particle was far less for multiple-particle pulses. Tobias and coworkers (*5*) also reported a dependence of the subject's ability to detect HZE particles that did not produce Cerenkov radiation on the number of particles in the pulse. Table 2 shows that the effect holds true for the diffuse flashes, which were shown above to be due to Cerenkov radiation and hence optical phenomena.

In summary, carbon nuclei entering the eye are detected more often at speeds above the Cerenkov threshold than below. This finding lends strong support to the hypothesis that Cerenkov radiation plays a major role in the visual phenomena observed by astronauts in deep space. Large diffuse flashes are observed only at speeds above threshold and occur only at the location in the field of view corresponding to beam exit. They are similar in appearance to the large-area flashes previously observed with muons and pions. These data suggest that an important mechanism for these large flashes and possibly for those observed in space is Cerenkov radiation. Furthermore, the large flashes observed in space can be generated by nuclei with atomic numbers as low as 6 and not only by nuclei of higher atomic number.

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Deuterated Methane Observed on Saturn

Abstract. *Absorptions for the ν_2 band of deuterated methane (CH_3D) have been observed in the 5-micron spectrum of Saturn, obtained with a Fourier transform spectrometer. Analysis of the band yields a CH_3D abundance of 2.6 ± 0.8 centimeter-amagat and a temperature of 175 ± 30 K for the mean level of spectroscopic line formation. This temperature indicates that a substantial portion of Saturn's flux at 5 microns is due to thermal radiation, and that we are therefore looking fairly deep into its atmosphere, as is the case for the Jupiter 5-micron window. This CH_3D abundance leads to a deuterium/hydrogen ratio of about 2×10^{-5} in Saturn's atmosphere. This ratio is much lower than the terrestrial value but comparable to that determined for Jupiter and may be taken as representative of the deuterium/hydrogen ratio in the solar system at the time of its formation.*

Observations of the deuterium content in the atmospheres of the major planets is important for a determination of its abundance at the time of formation of our solar system. Present theories (*1, 2*) indicate that deuterium can only be produced during "big bang" nucleosynthesis. A determination of the primordial D/H ratio, therefore, poses important experimental constraints such as the mass density, the rate of expansion, and the neutron-proton density for theories of nucleosynthesis and the formation of the universe. Stellar processing of matter has the effect of destroying deuterium, and the sun and stars have thus burned most of their deuterium into ^3He. The value of the D/H ratio obtained from the massive hydrogen atmospheres of the major planets may be taken as most representative of a "primordial" D/H ratio since their deuterium has probably undergone very little reprocessing (*2*) and is not affected by fractionation in the interior (*3*).

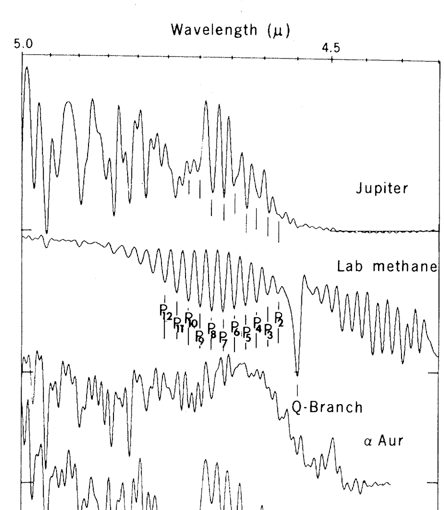

Fig. 1. A portion of the 5-μ spectrum of Saturn at a resolution of 2.8 cm^{-1}. A comparison star (α Aur), a laboratory CH_4 spectrum, and a spectrum of Jupiter in the same region are also shown. The Q-branch and P-branch lines of the ν_2 band of CH_3D are marked. Zero levels are displaced as indicated on the side.

Several years ago deuterium in the form of CH_3D was detected in the atmosphere of Jupiter by Beer *et al.* (*4, 5*). Their estimates of the jovian D/H ratio ranged between 2.8×10^{-5} and 7.5×10^{-5}. Sometime thereafter, the very weak 4-0 P(1) line of HD, observed in the jovian spectrum by Trauger *et al.* (*6*), allowed a direct comparison between the HD and H_2 abundances and gave a D/H ratio of 2×10^{-5}. The actual value for the D/H ratio in Jupiter's atmosphere is, at present, still uncertain because of correction effects introduced by the scattering nature of its atmosphere (*7*) and because of the recent revisions (*8*) of both the HD and H_2 line strengths used in the determination of the D/H ratio. Presently accepted jovian D/H values center around 5×10^{-5} (*9*).

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Table 1. Determination of the D/H ratio.

Measurement	Pressure (atm)	Temperature (K)	Overlying abundance: H_2 (km-amagat)	Overlying abundance: CH_4 (m-amagat)
Radiative-convective boundary	0.53	114	47	43
Mean level of 5-μ line formation	1.85	175	200	150
Base level of 5-μ line formation	3.9	220	400	300
Observed CH_3D (cm-amagat)				2.6
CH_3D/CH_4				9×10^{-5}
D/H				2×10^{-5}

We report here the detection of CH_3D in Saturn's atmosphere. The observations were made in December 1976 at the Catalina Observatory 154-cm (61-inch) telescope with a Fourier transform spectrometer described by Larson and Fink (*10*). A portion of Saturn's 5-μ spectrum (2.8-cm^{-1} resolution limit) containing the ν_2 band of CH_3D is shown as the bottom curve of Fig. 1. The curve above it, that of the solar-type comparison star α Aurigae, provides the strengths and locations of the telluric absorptions that occur in that region. A laboratory spectrum of 95 m-amagat of CH_4, and thus containing about 5.7 cm-amagat of CH_3D, indicates the positions and general appearance of the lines in the ν_2 band. The P-branch lines and the Q-branch are marked in Fig. 1. At the top, a 5-μ spectrum of Jupiter (which has been reduced to the same resolution as the Saturn spectrum) is shown for comparison, since it also displays the ν_2 CH_3D band. The Q-branch and lines from P(2) to P(8) can clearly be identified in the spectrum of Saturn and are marked in Fig. 1. The Saturn spectrum also contains absorptions due to phosphine (PH_3) which will be discussed elsewhere (*11*).

Closer inspection of the CH_3D lines on Saturn shows that their intensities fall off much faster with increasing rotational quantum number than their laboratory counterparts. The mean temperature of line formation on Saturn must therefore be lower than the ambient laboratory temperature of 295 K. This visual impression is made quantitative with a Boltzmann plot. In this plot, the equivalent widths of the lines, after correction for any blends or possible saturation effects, are divided by the appropriate statistical weights and Hönl-London factors and are plotted against the energy of the lower state. The slope of such a graph is proportional to the reciprocal of the temperature, and the intercept is related to the abundance. The results of this analysis are shown in Fig. 2. Ground state molecular constants of Olson (*12*) were used for CH_3D. The top curve is a test with our laboratory data to ensure that the P-branch of the ν_2 band is not affected by Coriolis intensity perturbations. The expected temperature of 295 K resulted. The middle curve is an analysis of the CH_3D absorptions on Jupiter based on the use of data of higher resolution (0.6 cm^{-1}), obtained with the Kuiper Airborne Observatory (*13*), which are almost completely free of telluric interference. The derived temperature of 220 ± 20 K is in good agreement with an estimate of 220 K obtained for the same band by Beer and Taylor (*14*).

The bottom curve for Saturn yields a temperature of 175 ± 30 K. Saturation of the lines was not considered in this determination but should not be a problem since the pressure in the line-forming region is at least 1 atm (see Table 1). Our temperature of 175 K is in good agreement with earlier 5-μ brightness temperature measurements of 176 and 190 K (*15*). These measurements required an albedo of ~1 to explain the high brightness temperature. The present determination refers to an actual atmospheric temperature and indicates that a substantial portion of the observed flux in Saturn's 5-μ window comes from thermal emission. Our temperature is considerably higher than the effective blackbody temperature of 95 K for Saturn (*16, 17*) or the temperature of ~110 K observed in the 10-μ region of its spectrum (*18*). We conclude that we are looking deeper into Saturn's atmosphere at 5 μ than in other atmospheric windows. Thus Saturn's 5-μ radiation is similar to that of Jupiter, although the detailed physical picture of their atmospheric and cloud structure will almost certainly contain individual differences.

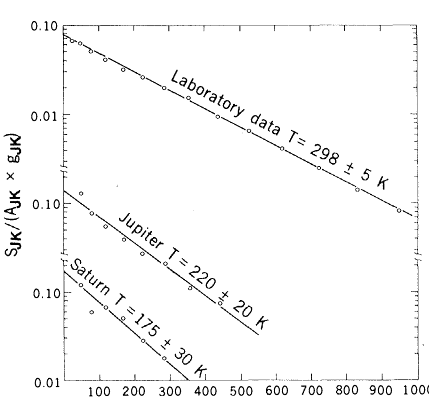

Fig. 2. A Boltzmann plot of the line strength divided by the Hönl-London and statistical weight factors as a function of the lower state energy.

An abundance of 2.6 ± 0.8 cm-amagat of CH_3D was derived from the intercept of the Saturn plot in Fig. 2. A band strength of 15 cm^{-1} per centimeter-amagat for the ν_2 band of CH_3D, representing an average between our laboratory measurement and Beer and Taylor's value (*5*), was used in this determination. The Boltzmann plot procedure implicitly presumes a simple transmitting or reflecting layer model which probably does not correspond to the exact mechanism of line formation in Saturn's atmosphere. It should, however, yield a good first-order determination for the CH_3D abundance. Corroboration of this statement is found from the plot of the Jupiter data in Fig. 2, which resulted in a CH_3D abundance of 2.5 ± 0.5 cm-amagat. This value is almost exactly the same as the result of Beer and Taylor (*5*) (2.6 ± 0.3 cm-amagat), who used a complex radiative transfer model, and it is close to a later value of 4 ± 1 cm-amagat obtained by the same investigators (*14*) from a more recent spectrum.

In order to proceed from an observed amount of CH_3D to a D/H mixing ratio, we have to compare the observed CH_3D value to the column density of CH_4 at the same level of the atmosphere. The most direct procedure is a comparison with lines of a weak band of CH_4 close by in frequency, but no such band could be found near 5 μ. The CH_4 bands in the visible or the $3\nu_3$ band at 1.1 μ are not appropriate comparisons because they probe shallower levels of the atmosphere.

The level of penetration for 5-μ spectral line formation is given by our derived rotational temperature. We estimate the amount of CH_4 for this level by recourse to models of Saturn's atmosphere (*16, 17*). One of the results of the model by Caldwell (*17*) is the level of the radiative-convective boundary on Saturn. This level and the model are constrained by such observations as the effective temperature of Saturn, the appearance and temperature of Saturn's 10-μ spectrum, and the observed H_2 abundance, so that the model should be a reasonably close approximation to Saturn's atmosphere. From the radiative-convective boundary downward we use the adiabatic temperature gradient ($He/H_2 = 0.2$) to obtain a CH_4 abundance of 150 m-amagat for the mean level of CH_3D spectroscopic line formation. The pertinent parameters for our analysis are listed in Table 1. According to the Curtis-Godson approximation (*19*) for a simple transmitting or reflecting atmosphere, the base level of spectroscopic probing is twice this value and a mixing ratio of 9×10^{-5} for CH_3D/CH_4 is obtained. This mixing ratio assumes a solar C/H ratio on Saturn (*20*), instead of an enrichment by a factor of 3 over the solar abundance as has been suggested by some (*16, 17, 21*). Assuming no chemical deuterium fractionation exchange between CH_4 and H_2, we obtain a D/H ratio of 2×10^{-5} for the Saturn atmosphere.

Because a number of observational facts and model parameters were required to derive this ratio, we now discuss our error estimate and give a brief description of the major factors contributing to the uncertainties in the derived D/H ratio. Beer and Taylor (*5*) have estimated the chemical fractionation of CH_3D on Jupiter and calculated a range of possible fractionation factors between 1.22 and 1.36. Subsequent detection in Jupiter's atmosphere of CO (*22*), PH_3 (*13*), and GeH_4 (*23*) has shown, upon comparison with the thermodynamic equilibrium calculations (*24*), that Jupiter's atmosphere must be strongly convective to the 1000 K level (*25*). At that temperature the fractionation factor is only 1.13. The detection of PH_3 in Saturn's atmosphere from the data of Bregman *et al.* (*26*) and Larson and Fink (*11*) indicates that Saturn's atmosphere is also convective to rather deep levels. Thus fractionation of the deuterium should not result in a significant correction to the D/H ratio. The accuracy of this number is largely determined by approximations and assumptions underlying the atmospheric models used (*16*), experimental errors in our temperature determination, uncertainties in the values for the H_2 line strengths (*8*), assumptions concerning the C/H mixing ratio, and the exact mechanism of CH_3D spectral line formation. We believe that the D/H ratio determined in this report is good to within a factor of 2, unless several of the above uncertainties fortuitously add together, in which case a somewhat higher systematic error might result (*27*).

Our observation of CH_3D on Saturn has shown that the 5-μ radiation originates from relatively deep levels within its atmosphere, and has provided a determination of the abundance of CH_3D on this planet. We have also obtained a value for the D/H ratio for Saturn. Our derived value is similar in magnitude to that of Jupiter. Both the Jupiter and Saturn D/H ratios are considerably lower than the terrestrial and meteoritic value of 15×10^{-5} (*28*). We have thus provided additional support for the earlier suggestion (*28, 29*), deduced from the $^3He/^4He$ ratio in the solar wind, that the earth and meteorites are considerably enriched in deuterium. If stellar processing of the deuterium that formed the solar system is minimal (*2*), the D/H ratio obtained for Jupiter and Saturn may be the most representative value determined so far for the primordial D/H ratio at the time of formation of the universe.

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Radiocarbon Dating with Electrostatic Accelerators: Dating of Milligram Samples

Abstract. *The recently developed direct counting technique for radiocarbon atoms has been used to measure the relative numbers of such atoms in various geological samples which had earlier been dated by the beta-ray counting method. Sample weights ranged from 3.5 to 15 milligrams. The dates determined by the two methods are consistent with each other. Further experience with the new method is also reported.*

The recent reports of successful detection of ^{14}C ions from recent carbon (*1–3*) have been followed by preliminary reports of the first attempts to date milligram samples (*4*) which had earlier been measured by the conventional beta-ray counting method. This report gives an account of the most recent comparative dating results and some of the experience gained from the work.

The apparatus used was essentially the same as that employed in our earlier reports (*1, 3, 4*) with the addition of an improved high-voltage stabilization system (*5*) which is essential for the work we report here. This is necessary because, in contrast to the conventional use of tandem accelerators for nuclear physics, current stabilization is not possible on the very weak ^{14}C beams. The tandem terminal voltage was stabilized to better than 0.1 percent to maximize the transmission of ^{14}C ions (*6*) through the high-resolution analysis system and to minimize the influence of nitrogen ions accelerated to the terminal as $^{14}NH^-$

Charcoal samples of known ages weighing several grams were obtained from the U.S. Geological Survey (*7*); 3.5 to 15 mg of these samples were compressed with an equal volume of KBr on aluminum cones. These cones, when inserted into a sputter ion source (*8*), gave $^{12}C^-$ currents in the range of 1.0 to 7.0 μA which were quite sufficient for these experiments. The surfaces of the carbon

