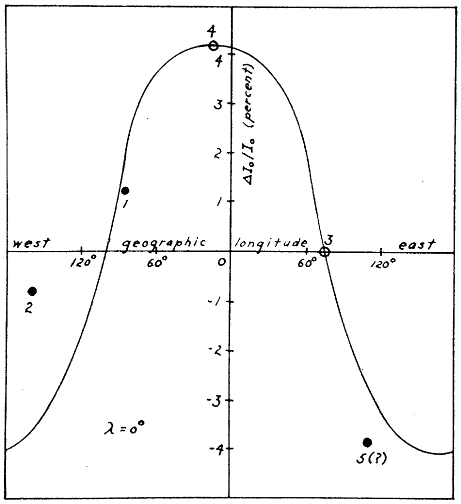

FIG. 6. The longitude effect along the geomagnetic equator.

tude effect at the geomagnetic equator is plotted in Fig. 6 together with the experimental points. The curve is symmetrical about the longitude 12 W approximately, but asymmetrical with respect to the axis of the abscissae.

With the exception of point 2 (SS route Honolulu to Melbourne at geomagnetic equator) it is seen that the agreement is very satisfactory.

The influence of atmospheric absorption will be considered in a future paper, but even without taking this factor into account it is seen from the above discussion that the theory is sufficiently in agreement with experiment. An additional factor which may affect the longitude effect is the bulging of the earth's atmosphere along the geographic equator due to the earth's rotation. Estimates of the magnitude of this effect are difficult to give at the present time, but in general it is clear that absorption would be greatest along the geographic equator and least at the poles. It is possible that the intensity at Lima may be affected by one percent due to this factor, as compared with the intensity at the west coast of Africa (SS lane Southampton to Cape Town at geomagnetic equator, point 4) but there seems to be no hope of accounting in this way for the high intensity measured by Millikan and Neher on the run from Honolulu to Melbourne, for there magnetic and absorption effects cooperate to give the least intensity.

We conclude that the theory of the latitude and azimuthal effects developed by Lemaitre and Vallarta is competent to account quantitatively for the longitude effect, and further that if the energy distribution function of the cosmic radiation which is responsible for these effects is substantially an exponentially decreasing function of the energy, the theory agrees with the measurements of the longitude effect.

My thanks are due to Dr. L. Bouckaert and Mr. E. J. Schremp who have helped me with the graphical integrations and with the discussion of the distribution function suggested in this paper.

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Difference Bands in the Spectra of the Major Planets

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This brief paper contains the first identifications of difference bands in planetary spectra. These absorption bands lie at 816$\mu\mu$, 802$\mu\mu$, 683$\mu\mu$, 673$\mu\mu$ and 584$\mu\mu$. They are due to methane gas and are found in the spectra of Jupiter, Saturn, Uranus and Neptune.

IT is now well established that the atmospheres of the giant planets (Jupiter, Saturn, Uranus, Neptune) contain vast amounts of methane (CH_4) in a large excess of hydrogen, and that in the two former ones there is also present a relatively small amount of ammonia (NH_3).[1]

[1] A. Adel and V. M. Slipher, Phys. Rev. **46**, 902 (1934); H. N. Russell, Science **81**, 1 (1935).

The temperatures[1] which prevail in these atmospheres are all well below $-100°C$, so that the percentage of molecules occupying excited vibrational states is indeed small. The overwhelming molecular population residing in the ground state can be appreciated from the following simple example. The ratio of the number of methane molecules excited thermally to the mode of vibration $\nu_2 = 1520$ cm^{-1}, to the number of methane molecules in the ground state is very nearly given by $2e^{-h\nu_2/kT}$, the factor two being present in virtue of the isotropic nature of ν_2 in two dimensions. In the Jovian atmosphere, above the clouds, where $T \leqq 163$, this ratio becomes $\sim 2e^{-13} = 1/200{,}000$; that is, about five molecules in every million are thermally excited to the ν_2 fundamental vibration.

Despite the small percentage population resident in excited states, the actual number of thermally excited molecules appears to be sufficient to render certain of these levels apparent in absorption. Consider, for example, the absorption band at $683\mu\mu$[2] which appears in the major planet spectrum. We have observed it also in the laboratory, leaving no doubt that it is due to the methane molecule. In structure it is very narrow, contrasting markedly with the broad regions occupied by most of the thirty-six planetary methane bands already identified as having arisen in transitions from the ground state.[1] The spectrum given below (Fig. 1) shows the $683\mu\mu$ band in the presence of several others. It was obtained in the laboratory with 2140 meter-atmospheres of CH_4, at 47.6 atmospheres and $T \leqq 293°$. The narrow nature of the $683\mu\mu$ band is what might be expected in a band arising in absorption from an excited state whose population is completely insufficient for the development of the P and R branches and only barely adequate to exhibit a trace of development in the Q branch.[3] Further evidence in support of this view is obtained from the fact that no plausible combination of frequencies can be found which would trace this band to a transition from the ground state, whereas it is at once correlated as a difference band; namely, as due to the transition from ν_2 to $6\nu_3$. This places the band $6\nu_3$ at 6187A in excellent agreement with observation.[1] Besides $6\nu_3 - \nu_2$ at $683\mu\mu$, there appears also in the spectrum of Jupiter a structurally similar band at $816\mu\mu$.[4] In the same way, this band is to be identified as $5\nu_3 - \nu_2$. By way of description, we may say very briefly that ν_2 is a symmetrical, double vibration, inactive in the infrared; and the sequence of bands $n\nu_3$ constitutes the strongest set in the major planet spectrum.

When we come to consider the probable appearance in the planetary spectra of other difference bands, it appears that just as $n\nu_3 + \nu_i$ gives rise to the strongest combination bands,[1] so the difference band sequence $n\nu_3 - \nu_i$ is the most likely to appear, in virtue of the great intensity of the set $n\nu_3$. n is any integer, and i, of course, may be 1, 2 or 4.[5] We have already discussed

[2] V. M. Slipher, Lowell Observatory Bulletin No. 42.

[3] In virtue of the spherical symmetry of the methane molecule all of its absorption bands possess P, Q and R branches.

[4] V. M. Slipher, Pop. Astron. **37**, 140 (1929).

[5] The methane molecule possesses the four fundamental frequencies of vibration: $\nu_1 = 2915$, $\nu_2 = 1520$, $\nu_3 = 3014$, $\nu_4 = 1304$ cm^{-1}.

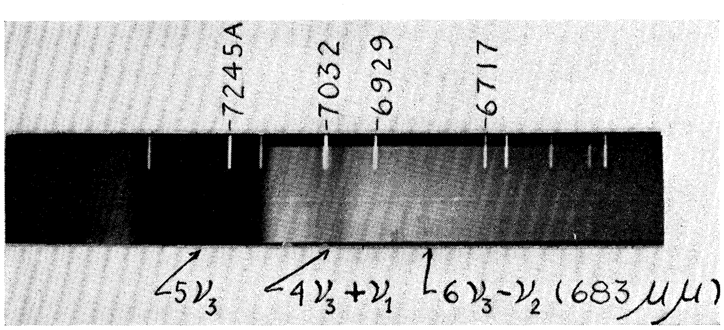

Fig. 1. Absorption spectrum of methane showing the $683\mu\mu$ band in the presence of several others.

the system $n\nu_3-\nu_2$; only the members $5\nu_3-\nu_2$ and $6\nu_3-\nu_2$ have been located. The system $n\nu_3-\nu_1$ may be expected to lie at approximately $921\mu\mu$, $754\mu\mu$, $644\mu\mu$ and $566\mu\mu$ for $n=5$, 6, 7 and 8, respectively.[6] $7\nu_3-\nu_1$ and $8\nu_3-\nu_1$ cannot be located in the spectra of the major planets. However, the spectra of Neptune and Uranus, where the bands $5\nu_3-\nu_1$ and $6\nu_3-\nu_1$ are most likely to be discovered, are unknown in this region.

We come finally to the group of bands $5\nu_3-\nu_4$, $6\nu_3-\nu_4$, $7\nu_3-\nu_4$ and $8\nu_3-\nu_4$, which may be expected to lie approximately at $802\mu\mu$, $673\mu\mu$, $584\mu\mu$ and $519\mu\mu$, respectively. The band $5\nu_3-\nu_4$ at $802\mu\mu$ is very prominent in the spectrum of Jupiter. In Uranus and Neptune, $6\nu_3-\nu_4$ is hidden by the mass of absorption $5\nu_3+\nu_1$,[2] while $7\nu_3-\nu_4$ is definitely present at $584\mu\mu$.[7]

It is evident that $n\nu_3-\nu_4$ is the strongest sequence with bands observable out to $n=7$: $n\nu_3-\nu_2$ is second, with n reaching to 6; while $n\nu_3-\nu_1$ is very weak and, thus far, completely unobserved in the planetary spectrum.[8]

The allocation of observed difference bands relative to the several planets is given in Fig. 2.

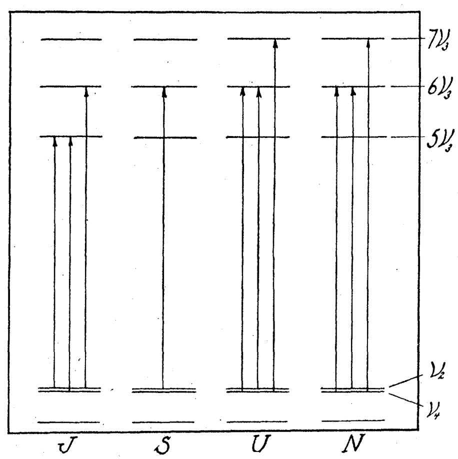

FIG. 2. Allocation of observed difference bands relative to the several planets.

[6] The absorption bands 5, 6, 7 and $8\nu_3$ are centered at approximately $726\mu\mu$, $619\mu\mu$, $543\mu\mu$ and $486\mu\mu$, respectively.

[7] V. M. Slipher, Lowell Observatory Bulletin No. 13.

[8] The correlation of these five difference bands brings the total of identified methane bands in the major planet spectrum to forty-one.[1]

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Provisional Wavelength Standards for the Extreme Ultraviolet

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This paper discusses the criteria for suitable wavelength standards in the extreme ultraviolet, and presents provisional values (obtained with a two-meter focus normal incidence vacuum spectrograph) for a number of lines of C, N, O and A falling in the spectral range between λ1850 and λ800. These are compared with the previous results of Edlén and of Bowen and of Bowen and Ingram. Further independent determinations are desirable. The present values, as those obtained by previous investigators, may be subject to a small systematic error inherent in the method of overlapping orders. This source of error is believed to be small, but must be eliminated before permanent standards can be established.

THE report of the commission on standards of wavelength of the International Astronomical Union contains the following criteria for auxiliary standards: "It is recommended that the mean wavelengths of the lines in certain groups of lines which give high orders of interference, and are satisfactorily distributed in the spectrum, and have been referred to the primary standard by three observers whose measurements are in satisfactory agreement, be adopted as working standards."[1] Tertiary standards are further defined as those obtained by interpolation between these secondary standards. It is well known that no standards which come anywhere near meeting

[1] Trans. Int. Astron. Union 1, 35 (1922).

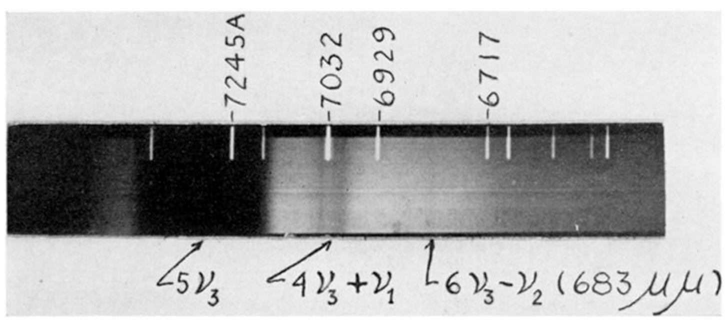

FIG. 1. Absorption spectrum of methane showing the $683\mu\mu$ band in the presence of several others.