THE IDENTIFICATION OF MOLECULAR SPECTRA

R.W.B. PEARSE
D.Sc., F.R.A.S.
Formerly Reader in Spectroscopy,
Imperial College, London

and

A.G. GAYDON
D.Sc., F.R.S.
Emeritus Professor of Molecular Spectroscopy,
Imperial College, London
Formerly Warren Research Fellow
of the Royal Society, Imperial College, London

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Preface to First Edition

These tables have been constructed with the aim of facilitating the identification of molecular spectra. Several excellent books have been written dealing with the theory of molecular spectra and some have included collections of molecular constants derived from the analysis of such spectra, yet it has hitherto remained necessary to search through original papers or to calculate the positions of bands from the tables of derived constants in order to identify a given system of bands. This task is usually tedious and sometimes impossible to one without considerable experience.

Originally we prepared for use in the laboratory a list of the wavelengths of the heads of a limited number of band systems which we frequently encountered as impurities in the course of spectroscopic research. This has proved so useful that it seems worth while to extend the list to cover, as far as possible, all known band systems. Since it appears, moreover, that such a list can be of service, not only to pure spectroscopists, but also to those who use spectroscopy as a tool for research in other fields such as astrophysics, chemistry and chemical technology, we have ventured to gather together in book form such information about known band spectra as may assist in their identification.

In the first list the bands were given in order of wavelength; all bands of the systems considered being included. This arrangement was soon found to possess practical disadvantages. A more useful arrangement was obtained by dividing the data into two sections. The advantages of the division are discussed in the introduction preceding the tables.

As a first stage in the compilation of the available data we have been obliged to limit the scope of the tables in several directions. Thus there are limits to the range of spectrum considered and to the complexity of the molecules whose spectra are included. The wavelength region considered is from 10000 Å to 2000 Å, that is roughly from the photographic infra-red to the ultra-violet limit of quartz spectrographs, except that in a few cases, where the origin of a system lies near the border line, one or two bands have been included which are just outside the range. As to complexity we have endeavoured to include all recorded systems of diatomic molecules, but only those of triatomic and more complex molecules which show well-defined banded structure and are of frequent occurrence in spectroscopic investigations. The absorption spectra of complex organic molecules and of solutions have been omitted.

In addition to the wavelengths of the band heads, the tables include information about the appearance and occurrence of each band spectrum. Though the information thus given is often useful for reference for other purposes, the object of identification has been kept foremost throughout in making decisions relating to the selection and arrangement of material.

For some systems we have found that the existing data are very incomplete. Where these systems are of frequent occurrence we have made new wavelength measurements. In a large number of cases where no estimates of intensities are given in the original paper, but a photograph is included, we have included estimates of intensities made from the photograph. In other cases where the analysis alone is given without mention of the positions and intensities of the most prominent heads, we have located the positions of the heads from the analysis where possible, and if necessary converted the corresponding wave-numbers to wavelengths. In this connection we should like to point out that it would be of great assistance for purposes of identification if authors of papers reporting new band systems would always in future include a brief description of the appearance of the system with wavelengths and intensities of the strongest heads, a few notes on the sources with which it is obtained, and, if possible, publish a photograph with a wavelength scale or a comparison spectrum.
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Finally, it is with pleasure that we acknowledge our indebtedness to the late Professor A. Fowler for a thorough introduction to the study of spectroscopy and for turning our attention to many of the spectra dealt with herein; to Professor H. Dingle for interest and encouragement in the preparation of these tables; to Dr. W. Jevons, Dr. R. W. Lunt, Dr. E. C. W. Smith, Dr. R. F. Barrow and Dr. R. C. Punshon for the use of spectrograms and unpublished data as well as for useful criticism during the preparation of the tables; and to Mr. E. S. Parke for valuable assistance in the preparation of the tables. One of us (A. G. G.) is also indebted to the Trustees of the Beit Fellowships for Scientific Research for a special grant during the tenure of which a large part of the manuscript was compiled.

R. W. B. P.
A. G. G.

LONDON.
SEPTEMBER 1940.

Preface to Fourth Edition

The first edition of this book appeared in 1941, the second in 1950, the third in 1963, and, as this sold out quickly, we had it reprinted with a 20-page supplement in 1965. This edition has been very fully revised. The first edition contained information about spectra of around 250 diatomic molecules and 35 polyatomic; this one covers about 490 diatomic and 127 polyatomic. Developments in techniques, such as flash photolysis, and interest in new subjects such as upper-atmosphere chemistry have contributed to the expansion of the amount of data available.

We have done our best to comb the literature up to about the end of 1974. Data listed are based on original publications, in some cases, on our own measurements, but the compilations edited by B. Rosen et al. (Données Spectroscopiques Relatives aux Molecules Diatomiques, 1970) and its supplement edited by R. F. Barrow et al. (Diatomic Molecules: A Critical Bibliography of Spectroscopic Data, 1973), the book by G. Herzberg (Electronic Spectra of Polyatomic Molecules, Van Nostrand, 1966) and the Berkeley Newsletters on Analysis of Molecular Spectra, prepared regularly by J. G. Phillips and S. P. Davis have been of great value in tracing references to the literature.

Although other works, such as that edited by Rosen, give constants and some data for diatomic molecules, and the book by Herzberg gives molecular constants for polyatomic molecules, this is still the only work aimed primarily at Identification, giving both diatomic and polyatomic molecules and including a considerable collection of reproductions of the actual spectra.

A. G. G.
R. W. B. P.

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AUGUST 1975.

Introduction

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The first section consists of a list of the most prominent heads of the more persistent and better-known band systems of each molecule. These heads are listed in order of wavelength, with abbreviated information about the direction of degradation of the bands and their appearance, and, of course, the molecule responsible. In earlier editions we made an attempt to include estimates of relative intensity of the heads within the system, listing these intensities under the sources in which the head was likely to be observed; however, since only the most prominent heads of each system were included, most of the intensities were '10' and in many cases information was not really adequate. This information about intensities has therefore been omitted from the first section in this Fourth Edition. This has enabled the table to be set more compactly.

The second section consists of individual lists of band heads for each system of each molecule, accompanied by notes about the occurrence and appearance of the system, the nature of the electronic transition involved, the vibrational assignment of the bands of the system, intensity estimates on a visual scale and references to the source of the data. The lists are arranged in alphabetical order of the chemical symbols of the molecules.

The general considerations leading to this division are briefly as follows. For practical reasons it is preferable to identify the molecular contribution to a given spectrum by system, rather than by band by band. It is the practice to identify the atomic contribution line by line, with the aid of tables of atomic lines in order of wavelength and there is a natural tendency to proceed to identify bands in a similar way. Such a procedure, however, often leads to incorrect identification. In an atom, each change of electronic state gives rise to a line, whereas in a molecule each change in electronic state gives rise to a whole band system. The various bands within the system arise from changes of the vibrational energy of the molecule and in general involve much smaller energy intervals than the electronic changes. Thus in respect of variation of intensity from source to source the bands of one system behave somewhat like the components of a fairly close multiplet, appearing and disappearing together. But whereas the multiplet contains relatively few lines of the whole spectrum, a single band system often contains many heads, perhaps several hundreds, and may comprise all the radiation that is readily excited for that particular molecule. Inclusion of all such bands in a single list leads to a large number of chance coincidences in wavelength. Such coincidences are more troublesome in the case of bands than in the case of lines, since the wavelength recorded for a band head is seldom as precise as that for an atomic line, depending, because of the structure of the head itself, very considerably on the judgement of the observer and on the dispersion used. This makes it much less safe to identify a single band by wavelength alone than it does to identify a single atomic line in this way. Supporting evidence should always be sought. Such evidence can be obtained by considering the system as a whole. The list of Section I has therefore been restricted to a few of the most prominent heads of each system so that it is somewhat analogous to the list of persistent lines of the elements. The purpose of the list is to provide a clue to the identity of an unrecognised system. The most prominent head of the unknown system is selected. This will usually be the front head of the strongest band, but not necessarily the strongest individual head for a multi-headed band. This head is then compared with the Persistent Heads list and a close agreement of wavelength and direction of degradation may suggest that it is a member of a certain system of a given molecule. Reference is then made to the individual list for
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that system and the presence or absence of other members is checked. The process is then continued with outstanding heads of the strongest of the remaining unidentified bands, and so on. It is also advisable to look for other systems of the molecules for which systems are found and also for systems of other molecules containing the same elements; thus if a system of C\textsubscript{2} is found and also one of N\textsubscript{2}, it is desirable to look for systems of CN as well as other systems of C\textsubscript{2} and N\textsubscript{2}. Or, again, if a trace of oxygen is suspected, systems of NO and CO may be checked. This procedure often leads to the discovery of weak bands, masked by stronger ones, which would otherwise have passed unnoticed. In following up other systems in this manner, and indeed in all cases where interest lies in the spectrum of a given molecule, the arrangement of Section II is especially convenient.

The actual number and choice of bands which should be included in the two lists is mainly a matter of experience to decide. We have tried to place most emphasis on those molecules which are cosmically abundant or are known to occur readily as impurities. Since the first edition of the book a very large number of new molecular spectra have been reported. In some cases this may almost degenerate to "stamp collecting"; studies of rare molecules involving unusual combinations of elements form convenient Ph. D. projects for students. However, it is often very difficult to predict what will and what will not be useful. For example the prominence of ZrO bands in some stellar spectra could hardly have been foreseen. Unusual molecules may arise from use of rare elements in transistor materials; development of special laser system may require unusual species; pollution by toxic heavy metals, like cadmium, may involve unusual spectra in their estimation.

For common molecules we have tended to give the prominent bands of all known systems; for the rarer species we have usually included only the strongest band or two of the strongest system in the first list of Persistent Heads, and not to give all systems but only a few bands of each in the second list, Individual Systems. Some band systems are very extensive, involving many bands of comparable intensity. These present special difficulty and it is not possible readily to identify such systems from the main Persistent Heads table.

It is well to emphasize that in making identifications, the evidence of the presence of atomic lines may be very helpful. To facilitate the checking of the presence of atomic tables of persistent lines of the elements has been included in the Appendix. If it is desired to check the line spectra more fully, recourse should be made to the various tables of atomic lines that are available.

Finally, in as much as direct comparison of photographs is the quickest and most certain way of identification, a number of plates are included showing many of the more frequently encountered band systems. Also those references to papers which contain a useful reproduction of the spectrum are indicated by a dagger, †, following the date.

### Table of Persistent Band Heads

The object of this table is to provide a clue to the nature of the unknown band system as quickly as possible, so that it may be compared directly with the appropriate detailed list or with one of the plates. For this purpose the list contains for all suitable band systems which are of frequent occurrence a few (sometimes only one) of the outstanding band heads, arranged in decreasing order of wavelength.

In this fourth edition the structure of this table has been substantially modified because of the increase in the number of known band systems. For the simplest systems with strong (0, 0) sequence we have included just this one head. In a greater number of cases we have included heads of the (0, 1), (0, 0) and (1, 0) sequences. For systems with more open Franck-Condon intensity parabola we have had to include more heads, but have kept the number down to the minimum. To include many heads not only makes the table long and expensive to set but increases the risk of chance meaningless coincidences.

Following the wavelength we have given a brief indication of the appearance of the head. This always includes the direction of degradation:

- R degraded to longer wavelengths (red)
- V degraded to shorter wavelengths (violet)
- or that the band measurement is for the maximum, M, of a headless band, or is the origin, O, of a band with a clear region near the origin and branches spreading in each direction from this origin.
- L indicates a very narrow, line-like, feature.

Other remarks in this appearance column are:
- CD. Close double head (separation usually less than 5 Å).
- CT. Close triple head.
- D. Double head.
- DCD. Double head, each component a close double.
- G. Group of four or more heads.
- L. Narrow band resembling an atomic line.
- T. Triple head.
- W. Accompanied by weaker head to the red.
- Wt. Accompanied by weaker head to shorter wavelengths (violet).

We should stress that we have usually given the first or most prominent head of the sequence, not necessarily the strongest. Some molecules have very extensive band systems consisting of many bands of comparable intensity and it has not been possible to include these. It often happens that homonuclear molecules have spectra of this type and examples are \textsubscript{5}As, \textsubscript{5}Br, \textsubscript{5}Cl, \textsubscript{5}I, \textsubscript{5}K, \textsubscript{5}Li, \textsubscript{5}Na, \textsubscript{5}P, \textsubscript{5}Se, \textsubscript{5}Te. Some mixed molecules of the same group of the periodic table also tend to give extensive systems, e.g. 1Br, 1Cl, 1NaK. We have also excluded from this table the very rare molecules, the collector's pieces.

In previous editions we listed intensities, often hypothetical, for the band in each of six sources. However, since we are always selecting just the strongest bands, these intensities were mostly 10 or 9 and not of much help, and since this arrangement took up a lot of space and required a lot of rather arbitrary decisions on our part, we have now dropped the inclusion of intensities from this list of persistent heads.

We have, however, retained the asterisk, *, to denote those bands which in our experience occur rather frequently as impurities in other spectra.

For those molecules possessing a number of strong systems, such as CO, N\textsubscript{2}, CN, we have given in very abbreviated form an indication of the system following the symbols for the
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C₄

The strongest system is the well-known Swan system in the green; this is due to a Π→Π transition, and two other triplet systems are known (Fox-Herzberg and Ballik-Ramsay). The ground state of C₄ is a singlet lying 610 cm⁻¹ below the lowest triplet level, and five singlet systems are known; that found by Mulliken is most readily observed, although the Phillips system in the least accessible near infra-red is probably stronger. The Destandes-d'Azambuja one is fairly strong.

We have retained the old notation but denoted the lower state of the Swan bands as X¹Π, and the lowest singlet as X¹Σ⁺ (formerly a¹Σ⁺). Some recent papers use capital for the singlets and lower case letters for triplets.

C₅

SWAN SYSTEM, A¹Π->X¹Πₜ

Occurrence. These bands are of very frequent occurrence in sources containing carbon. They are especially strongly developed in the greenish inner cone of a Bunsen or Meker burner flame, and in discharge tubes with high current density through hydrocarbon and other organic vapours. They also occur in a carbon arc, in active nitrogen reacting with organic vapours, in discharge tubes through H₄ + CO, and in both emission and absorption in shock tubes and furnaces. They have been reported in reactions between alkali metals and organic halides (e.g. Na + CCl₄). They are a prominent feature of comet and carbon-type stars.


References.

The following are all the main bands:

<table>
<thead>
<tr>
<th>λ</th>
<th>I</th>
<th>v', v''</th>
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<tr>
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<tr>
<td>5958</td>
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<td>2, 6</td>
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</tbody>
</table>

Tail Bands

Some weak ‘tail bands’, degraded to the red have been observed by Phillips and by Bugrim et al., λ₄9967 (13, 12), 49110 (12, 11), 4836-1 (11, 10), 4770-1 (10, 9), 4250-5 (11, 8), 4197-1 (10, 7) and 4179-9 (9, 6). The bands with origins at 4734 (9, 8), 4395 (8, 6) and 4123 (8, 5) are headless. Kini and Savadatt record 12 more weak heads.

High Pressure Bands

These occur in condensed discharges through CO at relatively high pressures (10 to 100 torr) and some special sources. They were initially treated as a separate system, but are now known to be part of the Swan system with v' = 6 selectively excited, probably by the reaction C + C₂O = C₅ (A²Π) + CO. They may occur without the ordinary Swan bands being present.

They are degraded to the violet, and under small dispersion usually appear double headed, perhaps due to anomalous rotational intensity distribution, but with larger dispersion the shorter wavelength head becomes less definite.

References.
R. C. Johnson and R. K. Asundi, P.R.S., 124, 668 (1929).
J. G. Fox and G. Herzberg, P.R.S., 2, 638 (1927).
### THE IDENTIFICATION OF MOLECULAR SPECTRA

**BEF (contd.)**

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**WEAKER SYSTEM, 1 – X 5Σ −**

The following are probably the strongest heads: 6λ5578-1 (2, 0), 5499-3 (3, 0), 5424-1 (4, 0), 5359-8 (5, 0), 5307-5 (6, 0).

### ETHYL BROMIDE FLAME BANDS

**Occurrence.** In flame of ethyl bromide and when Br₂ is added to the oxygen-hydrogen flame. They have also been observed in absorption following flash photolysis of Br₂ + O₂.

**Appearance.** Degraded to the red. The ν′ = 0 progression is conspicuous in emission and the ν″ = 0 in absorption.


The following are the emission bands from Coleman and Gaydon, with revised ν″ numbering:

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<tr>
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<th>I</th>
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The following are among the strongest absorption bands:

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### C₂

The strongest system is the well-known Swan system in the green; this is due to a 1Π₁ − 1Π ground state transition, and two other triplet systems are known (Fox-Herzberg and Ballik-Ramsay). The ground state of C₂ is a singlet lying 610 cm⁻¹ below the lowest triplet level, and five singlet systems are known; that found by Mulliken is most readily observed, although the Phillips system in the less accessible near-infra-red is probably stronger. The Desandres-d'Aszumabuca one is fairly strong.

We have retained the old notation but denoted the lower state of the Swan bands as X 1Π₁, and the lowest singlet as X 1Σ₊ (formerly a 1Σ₊). Some recent papers use capitals for the singlets and lower case letters for triplets.

### SWAN SYSTEM, A 2Π₁ − X 1Π₁

**Occurrence.** These bands are of very frequent occurrence in sources containing carbon. They are especially strongly developed in the greenish inner cone of a Bunsen or Meker burner flame, and in discharge tubes with high current density through hydrocarbon and other organic vapours. They also occur in a carbon arc, in active nitrogen reacting with organic vapours, in discharge tubes through He + CO, and in both emission and absorption in shock tubes and furnaces. They have been reported in reactions between alkali metals and organic halides (e.g. Na + CCl₄). They are a prominent feature of comets and carbon-type stars.

**Appearance.** Degraded to the violet. Marked sequences of single-headed bands. See Plate 9.


The following are all the main heads:

<table>
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<th>λ</th>
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<th>λ</th>
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<td></td>
</tr>
</tbody>
</table>

**Tail Bands**

Some weak ‘tail bands’, degraded to the red have been observed by Phillips and by Bugrim et al., λλ4996-7 (13, 12), 4911-0 (12, 11), 4836-1 (11, 10), 4670-1 (10, 9), 4255-0 (11, 8), 4197-1 (10, 7) and 4147-9 (9, 6). The bands with origins at 4734 (9, 8), 4395 (8, 6) and 4123 (8, 5) are headless. Kini and Savadatti record 12 more weak heads.

**High Pressure Bands**

These occur in condensed discharges through CO at relatively high pressures (10 to 100 torr) and some special sources. They were initially treated as a separate system, but are now known to be part of the Swan system with ν′ = 6 selectively excited, probably by the reaction C + C₂ = C₄ (A 2Π₁) + CO. They may occur without the ordinary Swan bands being present.

They are degraded to the violet, and under small dispersion usually appear double headed, perhaps due to anomalous rotational intensity distribution, but with larger dispersion the shorter wavelength head becomes less definite.


J. C. Fox and G. Herzberg, *P.R., 52*, 638 (1927).

### FOX-HERZBERG SYSTEM, B^1Π_u → X^1Π_g

**Occurrence.** Weakly condensed discharge through helium containing benzene vapour.

**Appearance.** Shaded to red.


<table>
<thead>
<tr>
<th>λ</th>
<th>ν', ν''</th>
<th>λ</th>
<th>ν', ν''</th>
<th>λ</th>
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<td>—</td>
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</table>

**FOXLIK-RAMSAY, FAR INFRARED SYSTEM, A^2Σ^- → X^4Π_u**

**Occurrence.** Emission from carbon-tube furnace. The system is likely to be strong in most sources but is too far in the infra-red to have been recorded so far from flames, etc.

**Appearance.** Marked sequences. Degraded to longer wavelengths.


<table>
<thead>
<tr>
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<th>λ</th>
<th>ν', ν''</th>
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<td>*2855</td>
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</tr>
</tbody>
</table>

* Band origin: probably fairly strong. ** Strong band.

### MULLIKEN SYSTEM, 2313 A, d^4Σ^- → X^2Σ^+_g

**Occurrence.** Emission in carbon arc, oxyacetylene flame and discharge tubes containing hydrocarbons. Also in absorption.


The headless (0, 0) band with single P and R branches spreading out from the origin at 2312-7 A is by far the strongest. Other weaker bands have been recorded. Origins:

### INDIVIDUAL BAND SYSTEMS

#### C^2 (cont.)

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<td>1</td>
<td>2312.7</td>
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<td>0</td>
</tr>
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</table>

**PHILLIPS NEAR INFRARED SYSTEM, B^3Π_u → X^3Σ^+**

**Occurrence.** Originally found in heavy-current discharges, but now known to be a strong feature in most systems including arcs and flames.

**Appearance.** Degraded to longer wavelengths with clear sequences. Strong Q branches and weaker P and R branches.


<table>
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<tr>
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<th>λ</th>
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<td>7714.6</td>
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</table>

* Band origin:

### DESLANDRES-D'AZAMBULI SYSTEM, C^4Π_u → B^4Σ^-_u

**Occurrence.** Condensed discharge through CO, CO₂ or C₂H₄, or through argon containing H₂, using carbon electrodes. In spark through liquid alcohol. In carbon arc in H₂ under high temperature conditions.

**Appearance.** Degraded to shorter wavelengths. Single headed.


This is a weak system. Intensities are relative to the strongest band of this system.

<table>
<thead>
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**Tail Bands**

Herzberg and Sutton obtained the following from an uncondensed discharge through He + C₂H₄.

They are degraded to the red:

3689.0 (6, 5), 3617.9 (5, 4), 3599.3 (4, 3), 3431.9 (5, 3).

**MESSERLE-KRAUSS BANDS, C^4Π_u → B^4Σ^-**

This is a weak system, observed mainly by its perturbations of overlapping Deslandres-d'Azambulil bands. The following are band origins. Degraded to the red:
C₃ (cont.)

In the following table the longer wavelength heads are by Johnson and Asundi, and the shorter, where given, by Fowler.

<table>
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<td>6, 4</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>5878</td>
<td>5</td>
<td></td>
<td>4353</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FOX-HERZBERG SYSTEM, B''Π₉₋X'Π₆

Occurrence. Weaker condensed discharge through helium containing benzene vapour.

Appearance. Shaded to red.


<table>
<thead>
<tr>
<th>λ</th>
<th>ν', ν''</th>
<th>λ</th>
<th>ν', ν''</th>
<th>λ</th>
<th>ν', ν''</th>
</tr>
</thead>
<tbody>
<tr>
<td>*2383</td>
<td>0, 6</td>
<td>2772-1</td>
<td>1, 3</td>
<td>2527-9</td>
<td>3, 2</td>
</tr>
<tr>
<td>*3129</td>
<td>0, 5</td>
<td>2731-5</td>
<td>0, 2</td>
<td>2486-3</td>
<td>2, 0</td>
</tr>
<tr>
<td>**2987</td>
<td>0, 4</td>
<td>2698-8</td>
<td>2, 3</td>
<td>2429-9</td>
<td>3, 0</td>
</tr>
<tr>
<td>2896-4</td>
<td>1, 4</td>
<td>2656-3</td>
<td>1, 2</td>
<td>2378-2</td>
<td>4, 0</td>
</tr>
<tr>
<td>**2855</td>
<td>0, 3</td>
<td>2589-0</td>
<td>2, 2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Probably fairly strong. ** Strong band.

BALLIK-RASMUS, FAR INFRA-RED SYSTEM, A''2Σ₋X'4Π₉

Occurrence. Emission from carbon-tube furnace. The spectrum is likely to be strong in most sources but is too far in the infra-red to have been recorded so far from flames, etc.


Reference. E. A. Ballik and D. A. Ramsay, Astrophys. J., 137, 61 (1963). Sequences heads, 24745 (0, 1), 17675 (0, 0), 14075 (1, 0) and 11724 Å (2, 0).

MULLIKEN SYSTEM, 2313 A, d''Σ₋X'2Σ₉

Occurrence. Emission in carbon arc, oxy-acetylene flame and discharge tubes containing hydrocarbons. Also in absorption.


J. G. Fox and G. Herzberg, F.R.S., 52, 638 (1937).

O. G. Landverek, F.R.S., 56, 769 (1939).


The headless (0, 0) band with single P and R branches spreading out from the origin at 2312-7 Å is by far the strongest. Other weaker bands have been recorded. Origins:

<table>
<thead>
<tr>
<th>λ</th>
<th>I</th>
<th>ν', ν''</th>
<th>λ</th>
<th>I</th>
<th>ν', ν''</th>
<th>λ</th>
<th>I</th>
<th>ν', ν''</th>
</tr>
</thead>
<tbody>
<tr>
<td>2414-8</td>
<td>0</td>
<td>1</td>
<td>2316-8</td>
<td>3</td>
<td>3</td>
<td>2315-4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>2314-0</td>
<td>1</td>
<td>1</td>
<td>2312-7</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PHILLIPS NEAR INFRA-RED SYSTEM, b''Π₉₋X'Π₆

Occurrence. Originally found in heavy-current discharges, but now known to be a strong feature in most systems including arcs and flames.

Appearance. Degraded to longer wavelengths with clear sequences. Strong Q branches and weaker P and R branches.


R heads:

<table>
<thead>
<tr>
<th>λ</th>
<th>ν', ν''</th>
<th>λ</th>
<th>ν', ν''</th>
</tr>
</thead>
<tbody>
<tr>
<td>15484-1</td>
<td>0, 1</td>
<td>8750-8</td>
<td>2, 0</td>
</tr>
<tr>
<td>12070-2</td>
<td>0, 0</td>
<td>8108-2</td>
<td>5, 2</td>
</tr>
<tr>
<td>10147*</td>
<td>1, 0</td>
<td>7907-7</td>
<td>4, 1</td>
</tr>
<tr>
<td>8980-5</td>
<td>3, 1</td>
<td>7714-6</td>
<td>3, 0</td>
</tr>
</tbody>
</table>

* Band origin

DESANGRES-D'AZAMBULBA SYSTEM, c''Π₆₋b''Π₆

Occurrence. Condensed discharge through CO₂, CO₂ or CH₄, or through argon containing H₂ using carbon electrodes. In spark through liquid alcohol. In carbon arc in H₂ under high temperature conditions.


This is a weak system. Intensities are relative to the strongest band of this system.

<table>
<thead>
<tr>
<th>λ</th>
<th>I</th>
<th>ν', ν''</th>
<th>λ</th>
<th>I</th>
<th>ν', ν''</th>
</tr>
</thead>
<tbody>
<tr>
<td>4102-3</td>
<td>0</td>
<td>1</td>
<td>3852-2</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>4065-1</td>
<td>6</td>
<td>1, 2</td>
<td>3825-6</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>4041-8</td>
<td>3</td>
<td>2, 3</td>
<td>3607-3</td>
<td>8</td>
<td>1, 0</td>
</tr>
<tr>
<td>4026-9</td>
<td>1</td>
<td>3, 4</td>
<td>3592-9</td>
<td>7</td>
<td>2</td>
</tr>
</tbody>
</table>

Tail Bands

Herzberg and Sutton obtained the following from an uncondensed discharge through He + C₄H₆.

They are degraded to the red:

3689 0 (6, 5), 36417-9 (5, 4), 3599-3 (4, 3), 3431-9 (5, 3).

MESSERLE-KRAUSS BANDS, c''Π₆₋b''Π₆

This is a weak system, observed mainly by its perturbations of overlapping Desangres-d'Azambula bands. The following are band origins. Degraded to the red:

<table>
<thead>
<tr>
<th>λ</th>
<th>I</th>
<th>ν', ν''</th>
<th>λ</th>
<th>I</th>
<th>ν', ν''</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>7521-8</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6006-6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4904-8</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>


This is a weak system. Intensities are relative to the strongest band of this system.

<table>
<thead>
<tr>
<th>λ</th>
<th>I</th>
<th>ν', ν''</th>
<th>λ</th>
<th>I</th>
<th>ν', ν''</th>
</tr>
</thead>
<tbody>
<tr>
<td>4102-3</td>
<td>0</td>
<td>1</td>
<td>3852-2</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>4065-1</td>
<td>6</td>
<td>1, 2</td>
<td>3825-6</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>4041-8</td>
<td>3</td>
<td>2, 3</td>
<td>3607-3</td>
<td>8</td>
<td>1, 0</td>
</tr>
<tr>
<td>4026-9</td>
<td>1</td>
<td>3, 4</td>
<td>3592-9</td>
<td>7</td>
<td>2</td>
</tr>
</tbody>
</table>
THE IDENTIFICATION OF MOLECULAR SPECTRA

C₃ (contd.)

\[ \lambda \quad I \quad \nu' \quad \nu'' \]
3779-6 weak 4, 6 3586-0 strong 0, 2
3672-7 mod. 5, 6 3396-1 strong 0, 1
3670-0 strong 2, 4

FREYMARK BANDS, \( \mathrm{e}^3\Sigma_u^- - b^3\Pi_u \)

Occurrence. Discharge through acetylene and probably in other sources.

Appearance. Degraded to shorter wavelengths. Apparently single headed, with clear sequences.

Reference. H. Freymark, Ann. Phys. (Lpz.), 8, 221 (1951).†

Heads (\( \lambda_0 \)) or origins (\( \lambda_0 \)):

\[ \begin{array}{cccc}
\lambda_0 & I & \nu' & \nu'' \\
2218/2 & 9 & 0, 1 & 2072/4 & 6 & 1, 0 & 2087/1 & 5 & 4, 3 \\
2216/6 & 7 & 1, 2 & 2079/6 & 6 & 2, 1 & 2096/9 & 4 & 5, 4 \\
2142/9 & 10 & 0, 0 & 2081/2 & 5 & 3, 2 \\
2142/6 & 1 & 1, 1 & \\
\end{array} \]

C₄⁺

MEINEL SYSTEM, 2490 A, \( \mathrm{E}^2\Sigma_u^- - \Pi_u \)

Occurrence. Absorption following a flash discharge through C₂H₂.

Appearance. Slightly degraded to the red. The only known band, the (0, 0), has a Q head at 2490-5, with P and R branches extending away from this.


The assignment to C₄⁺ is probable but not quite certain; C₂⁺ is a possibility.

C₅⁻

HERZBERG-LAGERQUIST SYSTEM, 6000–4800 A, \( \Sigma^2 \Sigma^- - \Sigma \Sigma^- \)

Occurrence. In emission and in absorption from flash discharges through CH₄ and in a shock tube.

Appearance. Marked sequences of single-headed bands. Degraded to the violet.


P heads with own estimates of intensity:

\[ \begin{array}{ccccc}
\lambda & I & \nu' & \nu'' \\
5984/8 & 4 & 0, 1 & 5363/3 & 6 & 1, 1 & 4833/8 & 5 & 3, 2 \\
5912/7 & 5 & 1, 2 & 4902/0 & 6 & 1, 0 & 4804/5 & 3 & 4, 3 \\
5844/6 & 2 & 2, 3 & 4866/4 & 6 & 2, 1 & 4779/1 & 2 & 5, 4 \\
5415/9 & 10 & 0, 0 & \\
\end{array} \]

C₅

THE 4050 A COMET-HEAD GROUP

This group was at one time attributed to CH₄ but later work using deuterium and C¹⁹ proved that the emitter is C₅.

INDIVIDUAL BAND SYSTEMS

C₅ (contd.)

Occurrence. Originally observed in the heads of comets, the group was later observed in various laboratory sources, including discharges through flowing hydrocarbons or between carbon electrodes in H₂ + Xe, or in a graphite hollow-cathode discharge. Also in rich hydrocarbon flames, hydrocarbon/fluorine flames, in shock waves and in absorption and emission in a carbon-tube furnace. The most detailed work has been done on flash-photolysis absorption (and fluorescent emission) of diazomethane.

Appearance. A complex group of narrow red-degraded bands. The appearance depends a lot on the dispersion used, rotational structure being observed at large dispersion. The main head is at 4049-77 A and is always prominent. Another head at 4072-4 is usually quite clear. The wavelength measurements in comets (Swings, flames (Kiss and Bass) and flash photolysis (Gausset et al.) do not agree at all well.


Gausset et al. list about 80 red-degraded heads between 4100 and 3440 A in flash photolysis of diazomethane. The following are extracted from this list:

\[ \begin{array}{cccc}
\lambda & I & \nu' & \nu'' \\
4098/5 & 1 & 3990/8 & 6 & 3935/8 & 3 & 3793/5 & 3 \\
4072/4 & 6 & 3983/1 & 4 & 3925/9 & 3 & 3656/8 & 3 \\
4049/8 & 10 & 3970/9 & 4 & 3914/5 & 3 & 3619/7 & 3 \\
4038/4 & 4 & 3965/9 & 3 & 3879/4 & 3 & 3524/9 & 3 \\
4018/3 & 4 & 3949/1 & 4 & \\
\end{array} \]

The C₅ molecule is linear and a full analysis has been made. The transition is \( \Phi_u^{-} - \Sigma_u^{-} \).

CBr

Occurrence. Absorption following flash photolysis of organic bromides.


3052 A SYSTEM, \( \Sigma^1 \Delta - \Sigma^1 \Pi \)

Appearance. Double-headed bands, degraded to shorter wavelengths, but Q₁ heads are diffuse due to predissociation.

Heads from Dixon and Kroto:

\[ \begin{array}{cccc}
\lambda & \nu' & \nu'' & \text{remarks} \\
3060/0 & 1 & 1 Q₁ & \text{weak head} \\
3052/3 & 0 & 0 Q₁ & \text{strong head} \\
3023/0 & 1 & 1 Q₁ & \text{weak maximum} \\
3014/5 & 0 & 0 Q₁ & \text{strong maximum} \\
\end{array} \]

Two diffuse bands at 2526 and 2496 observed by Tyerman.
FREYMARK BANDS, $e^1\Sigma^+_{g} \rightarrow b^1\Pi_u$

**Occurrence.** Discharge through acetylene and probably in other sources.

**Appearance.** Degraded to shorter wavelengths. Apparently single headed, with clear sequences.


<table>
<thead>
<tr>
<th>Heads ($\lambda_h$ or $\lambda_0$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_0$</td>
</tr>
<tr>
<td>3779-6 weak</td>
</tr>
<tr>
<td>3672-7 weak</td>
</tr>
<tr>
<td>3690-6 mod.</td>
</tr>
</tbody>
</table>

**C$_3$**

MEINEL SYSTEM, 2490 Å, $\Sigma^+_{g} \rightarrow \Pi_u$

**Occurrence.** Absorption following a flash discharge through C$_2$H$_2$.

**Appearance.** Slightly degraded to the red. The only known band, the (0, 0), has a Q head at 2490-5, with P and R branches extending away from this.


The assignment to $C_3^+$ is probable but not quite certain; $C_3^+$ is a possibility.

HERZBERG-LAGERVIST SYSTEM, 6000–4800 Å, $\Sigma^+_{g} \rightarrow \Sigma$

**Occurrence.** In emission and in absorption from flash discharges through CH$_4$, and in a shock tube.

**Appearance.** Marked sequences of single-headed bands. Degraded to the violet.


| P heads with own estimates of intensity: | $\lambda$ | $I'$, $I''$ |
|-----------------------------------------|---------|
| 3894-3 | 4 | 0, 1 |
| 5363-0 | 6 | 1, 1 |
| 4833-8 | 5 | 3, 2 |
| 4902-0 | 6 | 1, 0 |
| 4804-5 | 3 | 4, 3 |
| 4866-6 | 6 | 2, 3 |
| 4779-1 | 2 | 5, 4 |
| 3215-9 | 10 | 0, 0 |

**C$_3$**

THE 4050 Å COMET-HEAD GROUP

This group was at one time attributed to CH$_4$ but later work using deuterium and C$^{15}$ proved that the emitter is C$_3$.

**C$_3$**

**Occurrence.** Originally observed in the heads of comets, the group was later observed in various laboratory sources, including discharges through flowing hydrocarbons or between carbon electrodes in H$_2$ + Xe, or in a graphite hollow-cathode discharge. Also in rich hydrocarbon flames, hydrocarbon/flourine flames, in shock waves and in absorption and emission in a carbon-tube furnace. The most detailed work has been done on flash-photoysis absorption (and fluorescent emission) of diazomethane.

**Appearance.** A complex group of narrow red-degraded bands. The appearance depends a lot on the dispersion used, rotational structure being observed at large dispersion. The main head is at 4049-77 Å and is always prominent. Another head at 4072-4 is usually quite clear. The wavelength measurements in comets (Swings), flames (Kiss and Bass) and flash photolysis (Gausset et al.) do not agree at all well.


Gausset et al. list about 80 red-degraded heads between 4100 and 3440 Å in flash photolysis of diazomethane. The following are extracted from this list:

<table>
<thead>
<tr>
<th>$\lambda$</th>
<th>$\lambda$</th>
<th>$\lambda$</th>
<th>$\lambda$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4098-5</td>
<td>3990-8</td>
<td>3935-8</td>
<td>3793-5</td>
</tr>
<tr>
<td>4072-4</td>
<td>3983-1</td>
<td>3925-9</td>
<td>3655-8</td>
</tr>
<tr>
<td>4049-8</td>
<td>3970-9</td>
<td>3914-5</td>
<td>3619-7</td>
</tr>
<tr>
<td>4038-9</td>
<td>3965-9</td>
<td>3879-4</td>
<td>3524-9</td>
</tr>
<tr>
<td>4018-3</td>
<td>3949-1</td>
<td>4069-1</td>
<td>3724-3</td>
</tr>
</tbody>
</table>

The C$_3$ molecule is linear and a full analysis has been made. The transition is $^1\Pi_u \rightarrow ^1\Sigma_g^-$.

**CBr**

**Occurrence.** Absorption following flash photolysis of organic bromides.


3052 Å SYSTEM, A$_2\Delta \rightarrow \chi^\Pi$

**Appearance.** Double-headed bands, degraded to shorter wavelengths, but Q$_1$ heads are diffuse due to predissociation.

**Heads from Dixon and Krotko:**

<table>
<thead>
<tr>
<th>$\lambda$</th>
<th>$\lambda$</th>
<th>$\lambda$</th>
<th>$\lambda$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3060-0</td>
<td>1, 1 Q$_2$</td>
<td>weak head</td>
<td></td>
</tr>
<tr>
<td>3052-3</td>
<td>0, 0 Q$_1$</td>
<td>strong head</td>
<td></td>
</tr>
<tr>
<td>3023-0</td>
<td>1, 1 Q$_1$</td>
<td>weak maximum</td>
<td></td>
</tr>
<tr>
<td>3014-5</td>
<td>0, 0 Q$_1$</td>
<td>strong maximum</td>
<td></td>
</tr>
</tbody>
</table>

2500 Å SYSTEM, PROBABLY B$^2\Sigma^- \rightarrow \chi^\Pi$

Two diffuse bands at 2526 and 2496 observed by Tyeram.
The following are the strongest bands, observed by Margrave and Wieland in absorption:

<table>
<thead>
<tr>
<th>λ</th>
<th>I</th>
<th>λ</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>2118-7</td>
<td>3</td>
<td>2062-5</td>
<td>5</td>
</tr>
<tr>
<td>2101-7</td>
<td>3</td>
<td>2045-3</td>
<td>7</td>
</tr>
<tr>
<td>2099-9</td>
<td>4</td>
<td>2042-8</td>
<td>6</td>
</tr>
<tr>
<td>2083-3</td>
<td>3</td>
<td>2028-4</td>
<td>7</td>
</tr>
<tr>
<td>2075-9</td>
<td>5</td>
<td>2011-3</td>
<td>8</td>
</tr>
<tr>
<td>2063-5</td>
<td>6</td>
<td>2008-0</td>
<td>7</td>
</tr>
</tbody>
</table>

CH

Bands of CH are readily excited during the combustion of hydrocarbons and in electrical discharges where carbon and hydrogen are present. They are also observed in many astrophysical sources. These systems are known in the regions of 4300 Å, 3900 Å and 3143 Å respectively. Their intensities decrease in the order in which they are given, the third usually being much the weakest.

4300 Å SYSTEM, A'Δ − X'Π

**Occurrence.** In sources where carbon and hydrogen are present together such as flames of hydrocarbons, the carbon arc in hydrogen, discharge tube under a great variety of conditions and in active nitrogen when a hydrocarbon is introduced. It is also observed in emission from the heads of comets and in absorption in the Sun's atmosphere. Difficult to detect in absorption, but has been recorded in flash photolysis and the reaction zone of flames. Also in stars and interstellar space.

**Appearance.** Degraded to the violet. Usually the (0, 0) band is the only one to appear. The (1, 1) and (2, 2) are over laid by this (0, 0); a line-like feature at 4524 Å is the split up Q branch of the (2, 2). The (0, 0) shows strong Q heads and the lines of the P branch can be traced to about λ4385. Both branches consist of narrow doublets. See Plate 4.

**References.** L. Gerb., Z.P., 118, 27 (1941)


CH*

**DOUGLAS-HERZBERG SYSTEM, A''II − X'S**

**Occurrence.** Discharge, especially in hollow cathode, through helium with a trace of benzene or acetylene.

**Appearance.** Open rotational structure, with single P, Q and R branches. Degraded to the red; heads not well developed.


As the heads are not well developed, we list the Q(1) lines as well; these are close to the origins. No intensities are available, but the (0, 0) and (1, 0) bands are probably strong.
THE IDENTIFICATION OF MOLECULAR SPECTRA

CH (contd.)

CH

Bands of CH are readily excited during the combustion of hydrocarbons and in electrical discharges where carbon and hydrogen are present. They are also observed in many astrophysical sources. Three systems are known in the regions of 4300 Å, 3900 Å and 3143 Å respectively. Their intensities decrease in the order in which they are given, the third usually being much the weakest.

4300 Å SYSTEM, A^3Σ - X^2Π

Occurrence. In sources where carbon and hydrogen are present together such as flames of hydrocarbons, the carbon is in hydrogen, discharge tubes under a great variety of conditions and in active nitrogen when a hydrocarbon is introduced. It is also observed in emission from the heads of comets and in absorption in the Sun’s atmosphere. Difficult to detect in absorption, but has been recorded in flash photolysis and the reaction zone of flames. Also in stars and interstellar space.

Appearance. Degraded to the violet. Usually the (0, 0) band is the only one to appear. The (1, 1) and (2, 2) are overlaid by this (0, 0); a line-like feature at 4324 Å is the piled up Q branch of the (2, 2). The (0, 0) shows strong Q heads and the lines of the P branch can be traced to about λ4385. Both branches consist of narrow doublets. See Plate 4.

References. L. Gerô, Z.P., 118, 27 (1941)†.

CH^*

DOUGLAS-HERZBERG SYSTEM, A^3Π - X^1Σ

Occurrence. Discharge, especially in hollow cathode, through helium with a trace of benzene or acetylene.

Appearance. Open rotational structure, with single P, Q and R branches. Degraded to the red; heads not well developed.


As the heads are not well developed, we list the Q(1) lines as well; these are close to the origins.

No intensities are available, but the (0, 0) and (1, 0) bands are probably strong.

CH (contd.)

3900 Å SYSTEM, B^3Σ - X^2Π

Occurrence. Similar to the 4300 Å system.

Appearance. Degraded to the red. The (0, 0) band has a very open rotational structure. Other bands are obtained rather more readily than for the 4300 system, but rotational structure of bands with v' = 1 is curtained by predissociation. The (2, 1) band is usually absent, due to predissociation, but has been observed by Durie. See Plate 4.


ν', ν'' Q Heads I R Heads I
0, 1 4775.9 4794.0 1, 0 3954.4 3962.1
1, 1 4433.8 4444.4 3, 1 3967.1 3972.5
0, 0 4225.3 4237.6 2, 0 3743.7 3749.2
2, 1 4171.1 4178.4 4, 1 3806.1 3810.6

ν', ν'' Q Heads I
0, 1 4890.0 2
1, 2 4857.6 0
2, 2 4324 6
0, 0 4314.2 10

(4385) 5
The 3064 Å system of OH occurs very readily and is one of the commonest and best known band systems. A weak system has been found in the visible, and another in the ultra-violet, 2530–2250 Å. The rotation-vibration bands in the red and infra-red are known as the Meinel bands.

3064 Å SYSTEM, $A(2^3\Sigma^+)$ – $\chi(2^3\Pi)$

**Occurrence.** In emission from almost all sources where water vapour is present, such as flames, arcs and discharge tubes. Also in absorption in flames, flash photolysis, etc.

There is also a weak $R_3$ head. See Plate 4.


$v^\prime$, $v^\prime\prime$ $R_{23}$ $R_1$ $R_2$ $Q_1$ $Q_2$ $I$

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0</td>
<td></td>
<td>244</td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>2</td>
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</table>

Under some conditions (e.g. low-pressure hydrogen flame) bands with $v^\prime = 2$ are enhanced by an inverse predissociation process.

**VISIBLE SYSTEM (SCHULER AND WOELDIEKE) 5800–3700 Å, $B(2^3\Sigma^+) – A(2^3\Sigma^-)$**

**Occurrence.** This is a very weak system occurring in discharges through water vapour. It probably occurs in sun-spots.

**Appearance.** Open P and R branches; strongly degraded to the red.


No intensities are available but the (0, 7) and (0, 8) are relatively strong. R heads:

<table>
<thead>
<tr>
<th>$\lambda$</th>
<th>$v^\prime$, $v^\prime\prime$</th>
<th>$\lambda$</th>
<th>$v^\prime$, $v^\prime\prime$</th>
<th>$\lambda$</th>
<th>$v^\prime$, $v^\prime\prime$</th>
</tr>
</thead>
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<td>1, 7</td>
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</tr>
<tr>
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<td>0, 8</td>
<td>4729</td>
<td>0, 6</td>
<td>4216</td>
<td>1, 5</td>
</tr>
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<td>0, 7</td>
<td>4587</td>
<td>1, 6</td>
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</tbody>
</table>

**OH**

3565 Å SYSTEM, $A(2^3\Pi) – \chi(2^3\Sigma^-)$

**Occurrence.** Electrodeless and high-frequency discharges through water vapour at low pressure.
OH

The 3064 Å system of OH occurs very readily and is one of the commonest and best known band systems. A weak system has been found in the visible, and another in the ultra-violet, 2530–2250 Å. The rotation-vibration bands in the red and infra-red are known as the Meinel bands.

3064 Å SYSTEM, A²Σ⁺ – X²Π

**Occurrence.** In emission from almost all sources where water vapour is present, such as flames, arcs and discharge tubes. Also in absorption in flames, flash photolysis, etc.

**Appearance.** Degraded to the red. Four main heads R₁, R₂, Q₁, and Q₂; the Q₂ is rather overlapping.

There is also a weak R₂ head. See Plate 4.


<table>
<thead>
<tr>
<th>v', v''</th>
<th>R₂⁺</th>
<th>R₂⁻</th>
<th>Q₁</th>
<th>Q₂</th>
<th>I</th>
</tr>
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<tbody>
<tr>
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<td>2444</td>
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<tr>
<td>2, 1</td>
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<tr>
<td>3, 1</td>
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<td>2681-8</td>
<td>2681-8</td>
<td>2691-1</td>
<td>2</td>
</tr>
<tr>
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<tr>
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</tr>
</tbody>
</table>

Under some conditions (e.g. low-pressure hydrogen flame) bands with v'' = 2 are enhanced by an inverse predissociation process.

VISITABLE SYSTEM (SCHULER AND WOELDIEK) 5800–3700 Å, B²Σ⁺ – A²Σ⁺

**Occurrence.** This is a very weak system occurring in discharges through water vapour. It probably occurs in sun-spots.

**Appearance.** Open P and R branches; strongly degraded to the red.


No intensities are available but the (0, 7) and (0, 8) are relatively strong. R heads:

<table>
<thead>
<tr>
<th>λ</th>
<th>v', v''</th>
<th>i</th>
<th>v', v''</th>
</tr>
</thead>
<tbody>
<tr>
<td>5534-1</td>
<td>1</td>
<td>9</td>
<td>4957</td>
</tr>
<tr>
<td>5480-3</td>
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<td>4729-7</td>
</tr>
<tr>
<td>5123-5</td>
<td>0</td>
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<td>4587-3</td>
</tr>
</tbody>
</table>

OH²

ULTRA-VIOLET SYSTEM (SCHULER-MICHEL-BENOIST) 2550–2250 Å, C²Σ⁺ – A²Σ⁺

**Occurrence.** A very weak system observed in high frequency and other discharges through water vapour. Found in sun spots.

**Appearance.** Probably open P and R branches only; degraded to red.


R heads from Michel and from Carline and Dalby, with the latter authors values of v':

<table>
<thead>
<tr>
<th>λ</th>
<th>v', v''</th>
<th>i</th>
<th>v', v''</th>
</tr>
</thead>
<tbody>
<tr>
<td>2682-9</td>
<td>0</td>
<td>9</td>
<td>2464-7</td>
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<tr>
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<td>2544-7</td>
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<td>8</td>
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</table>

*These may be relatively strong.

MEINEL (VIBRATION-ROTATION) BANDS (X²Π)

**Occurrence.** In spectrum of the night sky, and in reactions of ozone with atomic hydrogen or with acetaldehyde. Under less conditions bands with v' = 8 and 9 are strong. Also in oxyhydrogen flames, when bands with lower v' are excited.

**Appearance.** Degraded to longer wavelengths. In cool sources, such as the night sky glow, the Q branch is strongest, with a few R lines closing up towards a weak head 20 to 50 Å on the short-wave side, and resolved P lines on the long-wave side. In hotter laboratory sources the R heads are better developed.


A. M. Bass and D. Garvin, *J. Mol. Spec.*, 9, 10 (1962)†.


R heads from Bas and Garvin in H + O₂ reaction; Q heads from older references. Intensities are our estimates from Broida and Garvin’s plate:

<table>
<thead>
<tr>
<th>λR</th>
<th>λQ</th>
<th>i</th>
<th>v', v''</th>
</tr>
</thead>
<tbody>
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OH²

3565 Å SYSTEM, A³Π – X²Σ⁺

**Occurrence.** Electrodeless and high-frequency discharges through water vapour at low pressure.