

THE IDENTIFICATION OF MOLECULAR SPECTRA

By

R. W. B. PEARSE, D.Sc., F.R.A.S.

*Assistant Professor and Reader,
Imperial College, London*

and

A. G. GAYDON, D.Sc.

*Warren Research Fellow of the Royal Society,
Imperial College, London*

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PREFACE TO SECOND EDITION

DURING THE TEN YEARS which have elapsed since the preparation of the first edition of these tables, many new papers on molecular spectra have appeared in the literature. When preparing the manuscript for this second edition we endeavoured to include new data up to 1947, but since then we have been able to insert in proof stage references and some new data as late as November, 1949. This has led to a very considerable increase in the amount of material included. In order to reduce the resulting increase in the number of pages we have, in many cases, arranged the tables in more compact form.

Many small modifications have been made as the result of further experience ; for some molecules the number of bands in the detailed lists has been increased ; for others the information about the appearance and occurrence has been amplified. We have also tended to increase the number of references as we realise that these are often useful for purposes other than identification, but we should emphasise that those dealing with details only of band structure or theoretical points are not usually given. The table of persistent heads has been extended, both by the addition of further bands from systems previously given in the individual lists, and also by the addition of bands from newly published papers (those up to about the end of 1947).

Four new plates containing 26 enlargements have been added, the new spectra shown including systems of O_2 , various hydrides and other molecules of general interest.

We should like to take this opportunity of expressing our thanks to the many authors who, either by private discussion or by sending reprints, have helped us to improve the book. We are thus indebted to Dr. R. F. Barrow, Prof. G. Herzberg, Dr. B. Rosen, Prof. P. Swings, Dr. K. Wieland and many others.

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

IMPERIAL COLLEGE,
LONDON, S.W.7.
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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 wave-lengths 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 wave-length; 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 wave-length region considered is from 10,000 Å to 2,000 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 this 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 wave-lengths 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 wave-length 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

PREFACE TO FIRST EDITION

necessary converted the corresponding wave-numbers to wave-lengths. 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 wave-lengths 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 wave-length scale or a comparison spectrum.

In addition to photographs which we have taken ourselves, we have been very fortunate in having access to numerous spectrograms taken by Professor A. Fowler and his colleagues and students in the Astrophysics Department of the Royal College of Science. Several of the reproductions of common band spectra have been taken from these plates.

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, Mr. R. F. Barrow and Mr. R. C. Pankhurst for the use of spectrograms and unpublished data as well as for useful criticism during trial of the tables, and to Mr. E. S. Parke for very valuable assistance in the preparation of the plates. 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.

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CONTENTS

	PAGE
INTRODUCTION	1
TABLE OF PERSISTENT HEADS	3
INDIVIDUAL BAND SYSTEMS	42
PRACTICAL HINTS	253
On the identification of bands — Sources — Collimation — Comparison spectra—Measurement—Spurious bands.	
DESCRIPTION OF PLATES	263
APPENDIX	265
Persistent atomic lines—Conversion of wave-lengths on Rowland's scale to International Angstroms—Conversion of wave-lengths in air to wave- lengths <i>in vacuo</i> —Physical constants.	
AUTHOR INDEX	270
SUBJECT INDEX	275

INTRODUCTION

EXPERIENCE in using the list of band heads arranged in order of wave-length showed that in extending it to include many more molecules a modification of form was desirable. The Tables for the Identification of Molecular Spectra are therefore divided into two sections.

The first section consists of a list of the strongest heads of the more persistent and better known band systems of each molecule in order of wave-length, together with information as to origin, intensity in various sources, and appearance.

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 in the system, and references to the sources 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, system by system, rather than 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 wave-length and there is a natural tendency to proceed to identify bands in a similar way. Such a procedure, however, frequently leads to incorrect identification. In an atom each change of electronic state gives rise to a line, whereas in a molecule each change of electronic state gives rise to a band system. The various bands of the system arise from changes of the vibrational state 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 several hundred bands 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 coincidences in wave-length which are merely fortuitous. Such coincidences are more troublesome in the case of bands than in the case of lines, since the wave-length recorded for a band head depends very considerably on the judgment of the observer and the dispersion used. This makes it much less safe to identify a single band by wave-length alone than it does to identify a single 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 strongest bands of each system so that it is somewhat analogous to the list of persistent lines of the elements. The actual number and choice of bands which should be included in this list is mainly a matter for experience to decide. The purpose of the list is to provide a clue to the identity of an unrecognised system. The strongest band of the unknown system is compared with the list, and a close agreement of wave-length 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 that system and the presence or absence of other members checked. The

process is then continued with 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 as well as for systems of other molecules containing the same elements. Thus if a system of C_2 is found and a system of N_2 , it is well to look for systems of CN as well as for other systems of N_2 and C_2 . Or, again, if a trace of oxygen is suspected, systems of NO and CO may be looked for. This procedure often leads to the discovery of weak bands, masked by stronger bands, 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. It is well also to emphasise that the evidence of atomic lines should not be neglected.

To facilitate the checking of the presence of atoms a table 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 had to the various tables of atomic lines that are available.

Finally, inasmuch as direct comparison of photographs is the quickest and most certain way to identification, a number of plates are included showing many of the more frequently encountered band systems.

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. For this purpose it contains, for all suitable band systems of frequent occurrence, a selection of the outstanding heads, which are most conspicuous under various conditions of excitation, arranged in order of wave-length. The actual number of bands of a system included is somewhat arbitrary, and the optimum can only be decided by extensive trial of the list. The general considerations are that there should be sufficient bands to provide a clue, whether the system is observed in emission or absorption, but not so many as to multiply unduly the possibility of chance coincidences. In a great number of cases, when the band system is composed of well-marked sequences, the requirements are well fulfilled by giving the first heads of the (1, 0), (0, 0) and (0, 1) bands. In other cases, however, where the molecular constants differ greatly for the two electronic states involved, the strongest bands are often far from the system origin and, moreover, those which are conspicuous in emission are weak in absorption, and *vice versa*. The Schumann-Runge bands of O₂ may be quoted as an extreme example of this behaviour. Then, again, the nature of the overlapping background of band structure decides to a considerable extent how conspicuous is a given head. Thus, the first head of a sequence is usually more outstanding than a slightly stronger head further along the sequence on account of greater contrast with the background and so is given preference. Similarly, in the case of close double or triple heads, it is usually the first head which is included in the list. In difficult systems the best selection can only be made from a series of photographs taken under various conditions. However, even if the absence of such photographs has in a few cases caused the omission of the *most* conspicuous head, nevertheless the heads included should be among the outstanding ones, so that by trial of two or three heads from the unknown spectrum a coincidence should be obtained.

Wave-lengths. In the first column are given the wave-lengths in air in International Angstroms, values being quoted, where possible, to the nearest 0.1 Å. Bands which are of particularly frequent occurrence as impurities are marked by an asterisk * before the wave-length. The letter R, V or M immediately following the wave-length indicates that the measurement is for the head of a band degraded to longer (red), shorter (violet) wave-lengths or is the maximum of a headless band respectively. The letter O is used in a few cases to signify that the wave-length recorded refers to the origin of the band.

Intensities. Intensities are eye estimates based on a scale of 10 for the strongest band of the system (or in a few cases for the strongest band of all the systems of that particular molecule), and they therefore usually refer only to the relative intensities of the bands within the system. Intensities printed in ordinary type are derived from actual experimental observations on the given source. Intensities given in italics are

estimates based on consideration of the vibrational distribution of intensity in other sources and imply that the band has been observed in the given source, but the observer has omitted to record intensities. Absence of a figure for intensity in any particular column merely indicates that the authors have no knowledge of the occurrence of the system in that source, but a dash, —, denotes that under normal experimental conditions the band is unlikely to occur in that source (*e.g.*, a band arising from a transition between two excited electronic states will not in general be observed in absorption at ordinary temperatures).

Sources. Intensities are listed for the following sources :—

- Ab. Absorption in vapour state.
- F. Emission in flame.
- A(a). Emission in an arc at atmospheric pressure, usually in air.
- A(r). In an arc at reduced pressure (frequently referred to as a vacuum arc). Bands occurring in arc sources are listed under only one of these (a) or (r), that which is more favourable to the band.
- D+ } In discharge tubes of various sorts. The + and - columns denote
- D- } whether the band appears more readily in the positive column or the negative glow respectively. Bands occurring in special discharges such as a high-frequency electrodeless discharge are usually listed in the positive column with an additional note under "Occ."

Appearance. Some indication of the appearance of the band is given in the last column but one, the following abbreviations being used :—

- CD. Close double head (separation $\frac{1}{4}$ -2 A.).
- CT. Close triple head (separation $\frac{1}{4}$ -2 A.).
- D. Double head (separation 2-15 A.).
- DCD. Double head, each component a close double.
- F. Group of four or five heads.
- Fd. Group of five heads appearing double with small dispersion.
- L. Narrow band resembling an atomic line.
- S. Head of a sequence or group of bands.
- T. Triple head (separation 2-15 A.).
- wr. Accompanied by weaker head to the red.
- wv. Accompanied by weaker head to the violet.

Occurrence. In the last column headed "Occ." some indications are given of special conditions or sources which are particularly favourable to the production of the band, the following abbreviations being used :—

- c. Mildly condensed discharge.
- e. Controlled electron source.
- f. Fluorescence.
- hf. Electrodeless high-frequency discharge.
- r. Ring discharge.
- t. Tesla coil.
- A. Favoured by presence of argon.
- H. " " hydrogen.
- He. " " helium.
- N. Excited by active nitrogen.
- Ne. Favoured by presence of neon.

TABLE OF PERSISTENT BAND HEADS

Very Extensive Systems. Some systems comprise a very large number of bands which differ little in intensity and cover a wide range of the spectrum. Because of the large number of bands which would have to be included for identification in the list of persistent heads they have in many cases been omitted. The extensive character of these systems in itself provides a clue to their identity.

The following is a list of the most important molecules which emit such extensive systems with the approximate region of the spectrum covered. Unless stated to the contrary, all these systems consist of bands degraded to longer wave-lengths (red).

As ₂	4300-2250 A.	Li ₂	7700-6600, 5000-4700.
Br ₂	> 8000-5100.	LiH	5000-3000.
CO flame (narrow headless)	6000-3000.	Na ₂	7000-6000, 5100-4800, 3500-2500.
Cl ₂	> 6000-4800.	NaH	5000-3700.
CsH	6500-5000.	NaK	9100-7200, 6000-5700, 5300-4900, 4000-3800.
H ₂	"many-line."	P ₂	3300-2000.
I ₂	> 8000-5000.	Rb ₂	7100-6700, 5200-4500.
IBr	> 7000-5500.	RbH	6500-5000.
ICl	> 8000-5700.	Se ₂	3700-3000.
K ₂	8900-7700, 7000-6200, 4500-4200.	Te ₂	4900-3900.
KH	5500-4000.		

The following molecules show extensive systems which are partly included in the table of persistent heads :-

CN	"Cyanogen red," 9400-4700.
CO	"Fourth Positive," 2800-< 2000.
N ₂	"First Positive," > 10,000-5000.
O ₂	"Schumann-Runge emission," 4400-< 2200.
O ₂ ⁺	"Second Negative," 6000-2000.
S ₂	6000-2800.
SO ₂	absorption 3400-2500.
SiF	6500-2500 (bands degraded both ways).
SiO	3000-< 2000.

	(Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
10826 R			10				BeO	Red	
10603.3 R				10	10		BaH		
10420 V					10		N ₂	1st Positive	T.S.
10052 R				10	10		BaH		
*9834.7 V			10				CaO		S.
9669 R		7					H ₂ O		
9647.5 R			8				BeO	Red	
9420 O	9						H ₂ O		
9277 R		10					H ₂ O		
*9229 V			8				CaO		S.
9098 R		10					BaCl		
9060 O	6						H ₂ O		
9017 R				10	10		BaH		
8924 R				10	10		BaH		
8916 R		7					H ₂ O		

THE IDENTIFICATION OF MOLECULAR SPECTRA

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
*8911.6 V	—	—			10		N ₂ 1st Positive	T.S.	
*8722.3 V	—	—			8		N ₂ 1st Positive	T.	
*8651.9			8				CaO		
8571.5 R		7	7				BaF	S.	
8563 O	5						HCN		
*8541.8 V	—	—			6		N ₂ 1st Positive	T.	
8420.8 R		10					BaCl		
*8406.0 R			1				LaO	S.	
8297 R		8	8				FeO		
8228 R		8	8				FeO		
8227 O	8						H ₂ O		
*8153.0			10				CaO		
8137 R		8	8				FeO		
8137.0 R		7	7				BaF	S.	
8106 R		10	10				FeO		
8097 R		8					H ₂ O		
7952 R			10				BeO		
7919 M	9						NH ₃		
7912 O	8						HCN		
*7910.5 R			8				LaO		
7879.3 R			10				CeO		
*7877.2 R			6				LaO	S.	
7852.5 V	—	—			3		C ₂ High Pressure	D.	c.
7833.9 R	—	—			3		CO Asundi	T.	
7831.8 R			10				CeO	S.	
7828.0 R			8				TiO γ		
*7753.2 V	—	—			6		N ₂ 1st Positive	T.S.	
*7715.7			4				CaO		
7672.1 R			8				TiO γ		
7628.1 R			7				TiO γ		
*7626.2 V	—	—			7		N ₂ 1st Positive	T.	
7593.7 R	10						O ₂ Atmospheric		
7589.6 R			7				TiO γ	S.	
7508 V				10	10		SrH		
*7503.9 V	—	—			7		N ₂ 1st Positive	T.	
*7403.5 R			10				LaO		
*7386.6 V	—	—			5		N ₂ 1st Positive	T.	
*7379.8 R			8				LaO	S.	
7350 V	—	10					NH ₃ ? Ammonia α		
7348.0 V				10	10		SrH		
7346.7 V				10	10		SrH		
*7318.5			2				CaO		
7297.2 R			10				CeO	S.	
7275.5 R			10				CeO		
7235.8 R			10				CeO	S.	
7227 O	5						H ₂ O		
7210.4 R	—	—			5		CO Asundi	T.	
7197.7 R			7				TiO γ		
7164.5 R		6					H ₂ O		
7125.6 R			10				TiO γ		

TABLE OF PERSISTENT BAND HEADS

7

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
7116.0 R	10	8	8				BaF	D.S.	
7087.9 R			9				TiO	γ	
7083.2 V	—	—			4		C ₂	High Pressure	D.
7054.5 R			7				TiO	γ	S.
7018.1 V				10	10		SrH		
7011.0 V	10						SrI		S.
*6994.5 R			1				LaO		S.
6984.7 V				10	10		SrH		
6942.6 V				10	10		CaH		
6930.2 V	10						SrI		S.
*6927.6 R		2	2		2		CN	Cyanogen Red	T. wv.
6922.0 R		2					H ₂ O		N.
6884.5 V		6	6				SrO ?		
6875.6 V		6	6				SrO ?		
6867.9 V		6	6				SrO ?		
6867.2 R	8						O ₂	Atmospheric	
6861.4 V		6	6				SrO ?		
*6856.3 V	—	—	—			8	O ₂ ⁺	1st Negative	
6850.2 V				10	10		BaH		
6847.7 V	10						SrI		S.
6804.0 R	—	—			8		CO	Asundi	T.
*6792.5 R		1	2		2		CN	Cyanogen Red	T. wv.
*6788.6 V	—	—			6		N ₂	1st Positive	T.
6782.8 R		8	8				BaO		
6767.8 V	10						SrI		S.
*6704.8 V	—	—			8		N ₂	1st Positive	T.
6689.5 V				10	10		BaH		
6685.7 R	—	—			7		CO	Asundi	T.
6666.7 V	10	10					SrBr		S.
6655.6 V	7	7	7				SrF		S.
6652 M	—	5					NH ₂	Ammonia α	
6651.5 R			4				TiO	γ	S.
6632.7 V	10	10	10				SrF		S.
*6631.6 R		4	9		9		CN	Cyanogen Red	T. wv.
*6623.6 V	—	—			9		N ₂	1st Positive	T.
6621.5 R			5				BiO		
*6620.3 V	—	—			7		CO	Angstrom	
6619.9 V	4	1	5				SrCl		S.
6613.7 V	10	10	10				SrCl		S.
6559.1 R			9				SbO		
*6544.8 V	—	—			10		N ₂	1st Positive	T.
6543.0 R			5				ZrO	γ	
6533.5			9				SmO		
6518.6 R					10		F ₂		
6516.8 M		5					H ₂ O		
6513.5 R	—	—			9		CO	Asundi	T.
6513.0 V	5	10					SrBr		S.
6512.0 V	10	10	10				SrF		S.
6510.9			10				SmO		
6508.1 R			9				ZrO	γ	

THE IDENTIFICATION OF MOLECULAR SPECTRA

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .		System.	App.	Occ.
6493.4 R			1				CuO			N.
6493.1 R		9	9	/			BaO			
6492 V					5		SiF	ξ		
6490.4 M		5					H ₂ O			
*6478.7 R		9	10		10		CN	Cyanogen Red	T. vv.	N.
6473.7 R			10				ZrO	γ		
*6468.5 V	—	—			10		N ₂	1st Positive	T.	
6468.0 M		5					H ₂ O			
6464.6 R	—	—			10		CO	Triplet		He. H.
6451.5 R		7	7				CrO			
6446.2 R			5				ScO			
6442.3 V	—				6		C ₂	High Pressure	D.	c.
6435 V					10		FeBr			hf.
6433.1 R	—	—			10		CO	Triplet		He. H.
6430.0 R			3				CuO			N.
6419.0 V		8	8				SrF		S.	
*6418.7 V	—	—	—		9		O ₂ ⁺	1st Negative		
6416 V					5		SiF	ξ		
6412.9 V	10	7					CaI		S. wr.	
6412.3 R			6				ZrO	γ		
6411.7 R			6				BiO			
6400.4 R		1	5				CuO			N.
6400 R					10		FeBr			hf.
6399.0 R	—	—			10		CO	Triplet	CD	He, H.
6398.7 R	—	—	—	—	10		He ₂			c.
6397 V					5		SiF	ξ		
*6394.7 V	—	—			9		N ₂	1st Positive	T.	
6394.3 R		9	9				CrO			
6389.3 V				10	10		CaH		D.	
6388.8 V	10	10					CaI		S. wr.	
6378.3 R			8				ZrO	γ		
6376.9 R			2				CuO			
6368 R	10	—	—	—	—		O ₂	Liquid		
6366.9 R	—	—			5		CO	Asundi		
6362.4 V	4	4	5				SrCl		S.	
6361.3 V	6	3					CaI		S. wr.	
6358.7 V	10	10	10				SrCl		S.	
6349.5			8				SmO			
6344.9 R			9				ZrO	γ		
6342.2 R		8	8				NiO			
*6332.2 R		10	9		9		CN	Cyanogen Red	T. vv.	N.
*6322.9 V	—	—			7		N ₂	1st Positive	T.	N.
6311.7 V			4				MgO			
6306.1 V		8	8				SrF		S.	
6302 M	—	5					NH ₂	Ammonia α		
6294.0 R		2	5				CuO			N.
6292.8 R			7				ZrO	γ		
6291.0 R		8	8				BaO			
6286.0 V	0	4					CaBr		S.	
*6285.3 V		3	3				CaF		S.	

TABLE OF PERSISTENT BAND HEADS

	Ab.	F.	A(a).	A(r).	D+.	D-.	System.	App.	Occ.
6278 V			4				CaO ?		
6277.7 V	10	10					CaBr	S.	
6276.6 R	3						O ₂	Atmospheric	
6265.9 V					8		NBr		N.
6260.9 R			8				ZrO	γ	
6258.8 V	0	5					CaBr	S.	
6258.5 V			9				CaO ?		
*6256.6 V		4	4				CaF	S.	
6252.9 V	10	10					CaBr	S.	
*6252.8 V	—	—			3		N ₂	1st Positive	T. N.
6250.7 R	1		8				PbO	A.	
6246.0 R		10					NiH		
6244.0 R	—	—			5		CO	Asundi	T.
6240.2 R			9				SbO		
6238.7 R	—	—	—			7	CO ⁺	Comet Tail	wv.
6231.1 V					8		NBr		N.
6229.4 R			9				ZrO	γ	
*6224.9 V	5	5	5				CaCl	S.	
6218.9 R		10	10				FeO		
6217.6 R			8				BiO		
6214.9 R			8				TiO	α	CT.
6211.6 V	10	10	10				CaCl	S.	
6193.4 V	5	5	5				CaCl	S.	
*6191.7 R		6	2		4		CN	Cyanogen Red	T. wv. N.
*6191.2 V		4	3		3		C ₂	Swan	S. c.
6189.4 R	—	—	—			7	CO ⁺	Comet Tail	wv.
6187 M					8		FeBr		hf.
*6184.9 V	10	10	10				CaCl	S.	
6180.5 R		9	9				FeO		
6161.5 R		9	9				CuO		N.
6159.1 R			10				TiO	α	CT.
*6157.4 R			1				LaO		CD. S.
6154.9 R		7	7				MnO	S.	
6146.8 R		4	8				CuO		N.
6133.3 R		8	8				NiO		
6132.1 R			10				YO		S.
*6122.1 V		3	4		4		C ₂	Swan	c.
6117.5 V				5			BiH		
6115.2 V						6	As ₂ ⁺		
6114.2 V		6	6				SrO ?		
6109.9 M		9	9				FeO		L.
6109.9 V		7	7				SrO ?		
6105.2 R	—	—			5		CO	Asundi	T.
6102.6 R					10		F ₂		
6101.3 V		7	7				SrO ?		
6097.3 M		9	9				FeO		L.
6097 V			10				CaO ?		
6096.8 R			8				YO		S.
6096.5 V		9	9				SrO ?		
*6086.9 V		5	5				CaF	S.	

THE IDENTIFICATION OF MOLECULAR SPECTRA

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
6086.4 R			8				VO		
6085.1 V		9	9				SrO ?		
*6079.9 V	—	—	—		8		CO	Angstrom	
6079.3 R			8				ScO		
6077.1 V		10	10				SrO		
6072.6 R			8				ScO		
*6069.7 V	—	—	—		7		N ₂	1st Positive	T.
*6064.4 V	8	10	10				CaF		S.
6064.3 R			7				ScO		
6064.0 V					10		FeCl		hf.
6060.3 V			6				MgO		
*6059.7 V		3	3		3		C ₂	Swan	c.
6059.3 R		10	10				CuO		N.
6051.6 R		10	10				CrO		
*6050.8 V	5	4	6				CaF		S.
6045.1 R		4	9				CuO		N.
6042 M	—	5					NH ₂	Ammonia α	
6039.6 R		9	9				BaO		
6039.1 R	0	4	7		7		S ₂		
6037.0 R	—	—	—		8		CO	Triplet	He. H.
6036.9 R		10	10				BiO		
*6036.9 V	8	7	6				CaF		S.
6036.2 R			10				ScO		
*6026.4 V	—	—	—		10		O ₂ ⁺	1st Negative	
6019.5 V					9		NBr		N.
6017.1 R			6				ScO		S.
*6013.6 V	—	—	—		7		N ₂	1st Positive	T.
6010.5 R	—	—	—		8		CO	Triplet	He. H.
*6006 V			8				CaO ?		
*6004.9 V		2	3		3		C ₂	Swan	c.
*6003 R			8				CaO ?		
5998.9 O	—	—	—		10		NO ⁺		
5993.8 V					8		BF		hf.
*5992.6 R		2	5		6		CN	Cyanogen Red	T. wv.
5992.6 V					9		As ₂ ⁺		N.
5990.7 V					10		NBr		N.
*5983 R			8				CaO ?		
5980.7 R	—	—	—		8		CO	Triplet	He. H.
5972.2 R			10				YO		S.
5962.4 V					10		NBr		N.
5962.2 R	0	5	6		6		S ₂		
*5959.0 V	—	—	—		8		N ₂	1st Positive	T.
*5958.7 V		1	2		2		C ₂	Swan	c.
5949.4 R			9				SbO		
5939.1 R			8				YO		S.
*5934.0 R	10	10	10				CaCl		S.
5933.8 V					10		NBr		N.
5910.7 R	3		10				PbO	A	
*5906.0 V	—	—	—		8		N ₂	1st Positive	T.
5905.0 V					10		NBr		N.

TABLE OF PERSISTENT BAND HEADS

11

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
5900.7 R	0	7	9		9		S ₂		
5899.3 V	—	—			8		C ₂	High Pressure	D.
5887.4 R			3				ScO		c.
5868.1 R		9	9				FeO		
*5866.3 R			4				LaO		CD. S.
5864.5 R		10	10				BaO		
5861.0 R	—	—	—		6		CO	Asundi	T.
5859.6 R		9	9				MnO		S.
*5858.2 R		2	8		9		CN	Cyanogen Red	T. wv.
*5854.4 V	—	—			8		N ₂	1st Positive	T.
5849.1 R			3				ScO		
5847.7 R			3				ScO		
5847.6 R			3				CuO		
5842.0 R			4				YO		S.
5840.6 R	0	7	9		9		S ₂		
5837.5 V					8		CoCl		hf.
5832.7 R			2				CuO		
*5830 R	0	4	5				CaF		
5826 R	9	—	—	—	—	—	O ₂	Liquid	
5822.1 V					10		BF		hf.
5815.1 V					8		BF		hf.
5814.7 V	—	—			5		N ₂	Green	wr.
*5809.9 R	3	4	4				CaCl		t.
5809.8 R			3				ScO		
*5804.3 V	—	—			7		N ₂	1st Positive	T.
5801.4 M					8		FeCl		hf.
5794.4 R		8	8				CrO		
5789.8 R		9	9				FeO		
5779.5 R	7	8	8				SrF		
5778.5 R			5				ZrO	β	
5775.5 V			5				MgO		
5772.0 R	7	8	8				SrF		S.
5763.4 R		9	9				PrO		S.
5758.5 R			4				TiO	α	CT. S.
*5755.2 V	—	—			7		N ₂	1st Positive	T.
5749.1 R	—	—	—		6		CO	Asundi	T.
5748.1 R			8				ZrO	β	
5737.9 M					10		CoCl		hf.
5736.7 R			10				VO		
5733.0 V	—	—	—	—	9		He ₂		c.
5731.4 R					9		F ₂		
*5730.2 R		5	8		7		CN	Cyanogen Red	T. wv.
5730 R		8					IO		
5724.0 R			6				ZrO	β	
5718.6 V					8		NBr		N.
5718.1 R			10				ZrO	β	
5713 M	—	5					NH ₂	Ammonia α	
5712.5 R		8					NiH		
5710.1 R	0	7	8		8		S ₂		
5701.0 R		8	8				BaO		

THE IDENTIFICATION OF MOLECULAR SPECTRA

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
5698.0 R			4				HfO	S.	
5697.8 R			5				YO	S.	
5695.1 V					8		NBr		N.
5694.3 V	8	8					CuF	A.	S.
5691.0 R		10	10				PrO	S.	
5677.8 R	5	10	10				PbO	A.	
5677 V					10		MnH		
5670.5 R	—	—	—		6		CO	Triplet	He. H.
5668.2 M					10		CoCl		hf.
*5653.1 V	—	—	—			2	N ₂ ⁺	1st Negative	He.
5651.6 R	0	7	10		10		S ₂		
5647.6 R	—	—	—		6		CO	Triplet	He. H.
5644.1 R		9	9				BaO		
5637.4 R					10		CoBr		hf.
*5635.5 V		9	8		8		C ₂	Swan	S. c.
*5631.9 V	—	—	—			9	O ₂ ⁺	1st Negative	
5629.3 R			6				TiO	β	CD.
5629.0 R			6				ZrO	β	
5621.7 R	—	—	—		6		CO	Triplet	CD. He. H.
5614.0 R		6	6				FeO		
*5610.2 V	—	—			10		CO	Angstrom	
5609.5 V	10	10					BaI		
*5599.9 R			10				LaO		CD. S.
*5598.3 R		3	3		3		CN	Cyanogen Red	T. wv. N.
5597.8 R			7				TiO	β	CD. S.
5596.6 R		8	8				PrO		
5595.0 V	—	—			3		N ₂	Green	F. t.
5586.4 R		10	10				MnO		S.
*5585.5 V		8	8		8		C ₂	Swan	c.
5582.8 R		6	6				FeO		
5567.0 R			8				TaO		
5563 R			10				PbH		
5551.7 R			5				ZrO	β	
5547.5 R			7				BO	α	CD. N.
*5540.7 V		5	6		6		C ₂	Swan	c.
5529.5 R		8	8				NiO		
5528.3 R					9		CoBr		hf.
5518.8 V			4				MgO		
*5515.6 V	—	—			2		N ₂	1st Positive	T.
5505.6 R			10				SbO		
*5501.9 V		3	4		4		C ₂	Swan	c.
5499.9 R	—	—	—			6	CO ⁺	Comet-tail	wv.
*5498 R			10				CaO?		
5497.1 R			5				TiO	α	CT.
5492.7 R		9	10				BaO		
*5478.5 V	—	—			2		N ₂	1st Positive	T.
*5473.3 R		2	5		5		CN	Cyanogen Red	T. wv. N.
*5473 R			9				CaO		
5472.8 R	0	7	9		9		S ₂		
5469.3 R			9				VO		

TABLE OF PERSISTENT BAND HEADS

13

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
5461.4 R	—	—	—			6	CO ⁺ Comet-tail	wv.	
5459.4 R	8	10	10				PbO A.		
5456.8 R					8		BF		hf.
5448.3 R			7				TiO α	CT. S.	
5443.4 R	10						TeCl ₂		
*5442.3 V	—	—			3		N ₂ 1st Positive	T.	N.
5436 M	—	5					NH ₂ Ammonia α		
5434.9 V	—	—			3		C ₂ High Pressure	D.	c.
5418.8 R	0	7	8		8		S ₂		
5410.5 R			3				AlO		
5407.7 R		8	8				NiO		
*5407.1 V	—	—			3		N ₂ 1st Positive	T.	N.
5394.8 R			3				AlO		
5393.9 R					7		F ₂		
5381.7 V	10	7					BaI		
*5380.4 R			2				LaO	CD. S.	
*5372.8 V	—	—			3		N ₂ 1st Positive	T.	N.
5372.6 R	10						PbSe A.		
5364 R	4	—	—	—	—	—	O ₂ Liquid		
5360.1 M	10	10	10				BaBr	S.	
5359.4 R		8	9				MnO	S.	
*5354.1 R		2	4		4		CN Cyanogen Red	T. wv.	N.
5353.6 R	8						TeCl ₂		
5352.0 R			7				PrO	S.	
5351.3 R	—	—	—		5		CO Triplet		He. H.
5349.7 R		7	8				BaO		
5333.8 R					10		SbCl		N.
5330.5 R	—	—	—		5		CO Triplet		He. H.
5326.9 V	—	—			3		N ₂ Green	F.	t.
5325.1 R	10						PbSe A.		
5309.5 V	—	—			5		N ₂ Green	wr.	t.
5307.5 R		10					IO		
5307.2 R	—	—	—		5		CO Triplet	CD.	He. H.
*5295.7 V	—	—	—			8	O ₂ ⁺ 1st Negative		
5293.4 R	5						Bi ₂		
*5291.0 R	10	10	10				CaF	CD. S.	
5278.7 R	10						PbSe A.		
5277.7 R			9				SbO		
*5262.3 R	4	6	6				CuCl A.	S.	N.
5258.2 R	5						Bi ₂		
5249.7 R	0	8	8		8		S ₂		
5240.5 R	10	10	10				BaCl	S.	
5240 V		10					Si ₂		
5240.0 R					10		AlCl		N.
*5239.3 R		2	3		3		CN Cyanogen Red	T. wv.	N.
5236.0 R					9		SbCl		N.
*5228.3 V	—	—	—			4	N ₂ ⁺ 1st Negative		He.
5224.1 R	5						Bi ₂		
5211 V				10	10		MgH		
5208.2 M	10	10	10				BaBr	S.	

THE IDENTIFICATION OF MOLECULAR SPECTRA

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
5205.5 R					10		AuCl		N.
5202.6 R	10						PbSe	A.	
*5198.2 V	—	—	—		10		CO	Angstrom	
5194.2 R	0	8	9		9		S ₂		
5185.0 R			7				ZrO ?	S.	
5174.5 R		10	10				NiO		
*5172.6 R				5	5		SiN	D.	N.
5166.9 R			7				TiO	α	CT. S.
*5165.2 V		10	10		10		C ₂	Swan	S.
5162.3 R	3	9	10				PbO	β	c.
5158.6 R	10						PbSe	A.	
5155.9 R					8		AuCl		N.
*5148.8 V	—	—	—			5	N ₂ ⁺	1st Negative	He.
*5145.4 R		2	2				CaF		CD. S.
5141.0 R					9		SbCl		N.
5141.1 R	6	7			7		CuI	A.	S.
5138 M	10	10	10				BaCl		S.
5131.0 R		9					IO		
*5129.3 V		7	6		6		C ₂	Swan	c.
5121.9 R					8		AuCl		N.
5102.1 R			5				AlO		
*5097.7 V		2	1		1		C ₂	Swan	c.
5096.7 R			4				ScO		
5081.0 M					10		MnBr		hf.
5079.3 R			4				AlO	S.	
5074.7 R			8				HfO		S.
5072.8 R	10	10			10		CuI	A.	S.
5072.1 R	—	—	—			5	CO ⁺	Comet-tail	wv.
5070.9 R	—	—	—		8		CO	Triplet	He. H.
5065.0 R			9				SbO		
5061.1 V	9	9					CuF	B.	S.
5060.1 R					5		N ₂	Vegard-Kaplan	e.
5054.4 R			7				BeO	Blue-Green	
*5053.6 V	—	—	—		2		N ₂	1st Positive	T.
5052.7 R	—	—	—		8		CO	Triplet	He. H.
5048.6 R					9		SbCl		N.
5040.1 R			6				BO	α	CD.
5039.7 R	—	—	—			5	CO ⁺	Comet-tail	wv.
5038.8 M					10		MnCl		hf.
5036.2 R	0	9	9		9		S ₂		
5031.7 R	—	—	—		8		CO	Triplet	CD.
*5030.8 V	—	—	—		2		N ₂	1st Positive	T.
5019.7 R	8	7			7		CuI	A.	S.
5013.2 R					8		NiCl		hf.
*5007.3 V		10	10				MgO		S.
5000.6 R	2		5				BaF		S.
*4996.7 V		8	9				MgO		
4993.5 R					8		MnBr		hf.
4992.1 R	2		5				BaF		S.
4990.8 V				10			BeH		

TABLE OF PERSISTENT BAND HEADS

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
4989.5 R	0	9	8		8		S ₂		
4983.8 R	5	10	10				PbO B.		
*4982.2 R	4	2	2				CuCl B.	S.	N.
4954.6 R			6				TiO α	CT. S.	
4950.8 R	4		10				BaF	S.	
*4946.1 R	4	1	1				CuCl C.	S.	N.
*4935.8 R		1	2		2		CN Cyanogen Red	T. wv.	N.
4932.0 V	10	10	10				CuF C.	S.	
4926.2 R			8				SbO		
4910.9 R	—	—	—		6		CO ⁺ Comet-tail	wv.	
4892.2 R		7					GdO	S.	
*4892.1 R	—	—			2		NO β	D.	N.
4885.5 M					8		FeCl		hf.
*4881.5 R	8	4	4				CuCl B.	S.	N.
4879.5 R	—	—	—		3		CO ⁺ Comet-tail	wv.	
4879.3 R	8	8					CuBr A.	S.	
4866.1 R			9				AlO		
4863.2 R			10				CeO	S.	
4857.8 R			5				ScO		
4850.6 R		6	6				BaO		
4850.5 R					4		SiF α		
*4846.9 R	8	3	3				CuCl C.	S.	N.
4844.5 R		10					IO		
4842.1 R			10				AlO	S.	
4842.1 R	0	9	10		10		S ₂		
4837.1 R					10		N ₂ Vegard-Kaplan		e.
*4835.3 V	—	—	—		10		CO Angstrom		
*4832.6 R		1	1		2		CN Cyanogen Red	T. wv.	N.
4823.5 R	—	—	—		8		CO Triplet		He. H.
4817.4 R			10				YO	CD. S.	
4816.9 R	8	10	10				PbO B.		
*4814.7 V	—	—			1		N ₂ 2nd Positive	CT.	
4810.4 R			8				TaO		
4806.7 R	—	—	—		8		CO Triplet		He. H.
4806 R			9				WO		
4804.3 R			5				TiO α	CT.	
4802 R	3	—	—	—	—	—	O ₂ Liquid		
4795.8 R			10				SbO		
4794.7 R	—	—	—		9		Cl ₂ ⁺	CD.	hf.
4794 R					5		MnH		
4794.0 R	—	—					CH ⁺		He.
4791.7 R			10				CeO	S.	
4790.6 R	0	9	9		9		S ₂		
*4788.5 R	5	2	2				CuCl B.	S.	N.
4787.3 R	—	—	—		8		CO Triplet		He. H.
4777 V	1		—		9		C ₂ H ₂ O ₂ glyoxal		t.f.
4775.9 R	—	—					CH ⁺		He.
4761.2 R			5				TiO α	CT. S.	
*4755.7 R	5	1	1				CuCl C.	S.	N.
*4752.5 V					3		AlH		

THE IDENTIFICATION OF MOLECULAR SPECTRA

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
4751-0 R		8	8				NiO		
4751-0 R	—	—	—		9		Cl ₂ ⁺	CD.	hf.
4744-0 R			8				BO	CD.	N.
*4737-1 V		9	9		9		C ₂	S.	c.
4732-6 R			9				BeO	Blue-Green	
4731-8 V				3			AlH		
4728-4 R	—	—			3		N ₂	Goldstein-Kaplan	T.
*4723-5 V	—	—			1		N ₂	2nd Positive	CT.
*4715-2 V		8	8		8		C ₂	Swan	c.
4711-2 R	—	—	—			5	CO ⁺	Comet-tail	wv.
4709-4 R			10				WO		
*4709-2 V	—	—				4	N ₂ ⁺	1st Negative	S.
4708-6 R			10				BeO	Blue-Green	He.
*4705-1 R				4	4		SiN		N.
4698 O				10	10		BiH	wr.	
*4697-6 V		6	7		7		C ₂	Swan	c.
4692-7 R			8				SrO		
4689-0 R				4			CuH		
*4684-8 V		3	4		4		C ₂	Swan	c.
4683-4 R	—	—	—			5	CO ⁺	Comet-tail	wv.
4682-6 R	—	—	—		10		Cl ₂ ⁺		hf.
4680-2 V	—	—	—		10		C ₂	High Pressure	D.
4673-4 R			9				SbO		c.
4673 R		8					BrO		
4672-6 R			2				SeO	S.	
4672-3 R			9				LuO		
4672-0 R			8				AlO		
*4670-9 V				4	4		AlH		
4665-7 R		5	5				NiO		
*4664-3 R				5	5		SiN		N.
4661-7 R			10				LuO	S.	
4661-3 V	—	—	—		5		CO	Herzberg	
4658-0 R	8	8	8				PbO	B.	
*4651-8 V	—	—	—			3	N ₂ ⁺	1st Negative	He.
4649-7 R					5		N ₂	Vegard-Kaplan	e.
4649-2 R			9				YO		CD. S.
4648-4 R				6			CuH		
4648-2 R			8				AlO	S.	
4637-9 R			10				ZrO	α	CD. S.
4633-3 R		8					GdO		
4631-4 V	6				7		AlH		S.
4630-6 R					5		CuI	C.	S.
4630 R	6						NO ₂		N.
4625-6 R	—	—	—	—	6		He ₂		D.
4619-8 R			8				ZrO	α	S.
4615-6 R		10					GdO		S.
4614-4 R			8				BiCl	Blue-Green	
4613-6 R	—	—	—		9		Cl ₂ ⁺		CD.
4612-7 R			10				BO	α	CD.
4609-8 R	1	8	8		8		S ₂		N.

THE IDENTIFICATION OF MOLECULAR SPECTRA

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
4486-3 R					5		CP B.	wv.	A.
*4482-4 R				6	6		SiN		N.
4480 M	10						NO ₂		
*4479-8 R	—	—			3		NO ₂	D.	N.
4477-9 R	10						CoH		
4470-5 R			2				AlO	S.	
4469-5 R			5				ZrO	α CD. S.	
4465-5 R	8				10		BiF		hf.
4464-9 R					8		BF		hf.
4462-6 R		4					GdO	S.	
4454-7 R					6		CP B.	wv.	A.
4448 R	8						NO ₂		
4447-6 M	—	7					CH ₂ O "Cool Flame"		f. t.
*4443-1 R				8	8		SiN		N.
4434-0 R					9		SbCl		N.
*4433-8 R	6	9	9		7		CuCl D.	S.	N.
4433-4 R	1	9	8		8		S ₂		
4432-3 R					4		N ₂ Goldstein-Kaplan	T.	t.
4430-2 R					7		SiF	α	
4427-3 R			6				BeO Blue-Green		
*4418-1 R			6				LaO	S.	
*4416-7 V	—	—			3		N ₂ 2nd Positive	CT.	
*4412-4 R	6	8	8		7		CuCl E.	S.	N.
4412 R	10	10	10				SrI	S.	
4410-8 R					5		CuI D.	S.	
4410-4 R	10	8	8				PbO B.		
*4406-9 R				8	8		SiN		N.
4403-9 R			10				CaO		
4400-5 R					7		SiF	α	
4399-6 R			10				SrO		
4398 R		10					BrO		
4393-8 R			6				AgO	D.	
*4393-1 V	—	—	—		8		CO Angstrom		
4390 R	8						NO ₂		
4384-8 R			10				CaO		
*4382-5 V		2	2		2		C ₂ Swan	S.	c.
4380-3 V	—	—	—		7		CO Herzberg		
4372-0 R	—	—		8			O ₂ Schumann-Runge		
*4371-9 R			4				LaO	S.	
*4371-4 V		3	4		4		C ₂ Swan		c.
4368-8 V	—	—			5		C ₂ High Pressure	D.	c.
4368-2 R					10		SiF	α S. wv.	
4366-7 R			9				CaO		
4366-7 R	10				10		BiF	S.	hf.
*4365-2 V		4	5		5		C ₂ Swan		c.
4365-0 R					9		SbCl		N.
4363-4 R			10				BO	α CD.	N.
4359-9 M	—	8					CH ₂ O "Cool Flame"		f. t.
4359-9 R					4		CuI D.	S.	N.
4355-9 R		9					IO		

TABLE OF PERSISTENT BAND HEADS

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.	
*4355-0 V	—	—			3		N ₂	2nd Positive	CT.	
*4353-9 R	9	10	10		9		CuCl	D.	S.	N.
*4353-1 R				7	7		AlH			
4351-2 R			9				CaO		S.	
4350 M	6						NO ₂			
*4343-6 V	—	—			4		N ₂	2nd Positive	CT. S.	
4341-1 R	10	10	10				CuBr	B	S.	
4339-4 R			8				BO	α	CD.	N.
*4333-2 R	10	9	9		10		CuCl	E.	S.	N.
4331-6 R					10		BH		L.	
*4317-6 R				5	5		SiN			N.
4316-0 R	—	—	—		7		Cl ₂ ⁺		CD.	hf.
*4315-0 V		3		3	3		CH			
*4312-5 V		10		10	10		CH			
4310-8 R	1	9	8		8		S ₂			
4307 R	6	10	10				SrI		S.	
4304-9 R					8		NiCl			hf.
4304-7 R			4				AgO		D.	
4299-1 V				10	10		ZnH			
4297-6 V				10	10		CdH			
4295-8 R	9				8		BiF		S.	hf.
*4293-7 R	—	—			3		NO	β	D.	N.
4291-8 R	—			9			O ₂	Schumann-Runge		
4289 R	5	10					CaI		S.	
4288-6 R	7	7	7				CuBr	B.	S.	
*4288-2 R	—	—			3		NO	β	D.	N.
4288 R							FeH ?			
4283 M				9	9		SiO ₂ ?			
4281-0 R			8				SrO			
*4280-9 R	7	9	9		6		CuCl	D.	S.	N.
4279-6 R				10			CuH			
*4278-1 V	—	—	—			10	N ₂ ⁺	1st Negative	S.	He.
*4277-0 R				5	5		SiN			N.
4274-3 R	—	—	—			10	CO ⁺	Comet-tail		
4272-7 R			10				SbO			
4272-0 R	—	—	—			10	CO ⁺	Comet-tail		
4270 R		10					BrO			
*4269-7 V	—	—			5		N ₂	2nd Positive	CT.	
4262-8 R	8	8	8				CuBr	C.	S.	
4262-8 R			6				AgO		D.	
*4259-5 R	10	10		10	10		AlH			
*4258-9 R	8	7	7		7		CuCl	E.	S.	N.
4256-6 R				8	8		SiO ₂ ?			
4254-4 R				7	7		SiO ₂ ?			
4252-4 R	—	—	—			8	CO ⁺	Comet-tail		
4252-1 R			10				HfO		S.	
4248-9 R	—	—	—			5	CO ⁺	Comet-tail		
4245-9 R					6		BH			
4242-8 M	—	9					CH ₂ O	"Cool Flame"		f. t.
*4241-0 R	10	10		10	10		AlH		D.	

THE IDENTIFICATION OF MOLECULAR SPECTRA

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
4240·8 R					7		SiF α	S. wv.	
4240 M				10	10		SiO ₂ ?		
*4239·1 R				9	9		SiN		N.
4237·6 R	—	—					CH ⁺		
4237·0 V				10	10		ZnH		
*4236·5 V	—	—				9	N ₂ ⁺	1st Negative	He.
4235·5 V				10	10		SiO ₂ ?		
4231·6 V	—	—	—			8	CO ⁺	Baldet-Johnson	wr. He.
4231·5 R	—	—	—			7	Cl ₂ ⁺	CD.	hf.
4228·5 V				9	9		SiO ₂ ?		
4227·1 V	4			4	4		BaH		
4225·3 R	—	—					CH ⁺		
4221·9 R				9			CaO		
*4216·0 V		9	9		9		CN	Cyanogen Violet	S. N.
4216·0 R					7		NiCl		hf.
4214·2 R	—			7			O ₂	Schumann-Runge	
4212·9 V	—	—	—			8	CO ⁺	Baldet-Johnson	D. He.
4211 R	2	10					CaI	S.	
4205·1 R			10				CaO	S.	
*4204·1 R				10	10		SiN		N.
*4200·7 R	—	—			4		NO	β	D. N.
*4200·5 V	—	—			6		N ₂	2nd Positive	CT.
*4199·1 V	—	—	—			4	N ₂ ⁺	1st Negative	He.
*4197·2 V		7	8		8		CN	Cyanogen Violet	N. N.
4194·7 R	—	—	—		7		Cl ₂ ⁺	D.	hf.
4193·6 R	2	9	8		8		S ₂		
4192·7 V					10		TiCl		S. wr. hf.
*4187·9 R	6	3	3		5		CuCl	E.	S. N.
4183·6 R					10		SbF		N.
*4181·0 V		5	7		7		CN	Cyanogen Violet	N.
4177·5 R			8				AgO		D
4172·7 R	—			9			O ₂	Schumann-Runge	
*4172·1 R				6	6		SiN		N.
4171·2 R					5		N ₂	Vegard-Kaplan	e.
4167·2 R			8				SrO		
4165·7 R	—	—			5		N ₂	Goldstein-Kaplan	T. t.
4159·5 R	—	—	—			5	CO ₂		e.
4157·0 R	2	8	7		7		S ₂		wv.
4154·4 R			10				TaO ?		
4143·4 R			6				BO α	CD.	N.
4143·1 R					8		NiCl		hf.
*4142·2 R				10	10		SiH		
*4141·8 V	—	—			5		N ₂	2nd Positive	CT.
4140·1 R	—	—	—		8		Cl ₂ ⁺	D.	hf.
4137·6 R	—	—	—			6	CO ₂		e.
4135·8 V	4	4	4				BaF		S.
4130·2 R			10				SbO		
4129·2 M	—	8					CH ₂ O	"Cool Flame"	f. t.
*4126·6 R				8	8		SiN		N.
4124·8 V	—	—	—		7		CO	Herzberg	

TABLE OF PERSISTENT BAND HEADS

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .		System.	App.	Occ.
4123·6 V	—	—	—		7		CO	Angstrom		
4123·6 R			10				AgO			
4120·8 R	—	—	—			6	CO ₂			e.
4118·9 R			6				HfO			
*4116·8 R				6	6		SiN	E.		N.
4115·8 R	—	—	—			9	O ₂ ⁺	2nd Negative		He.
*4113·6 R	—	—	—		4		NO	β	D.	N.
4112·1 R					10		SnBr			
4110·3 V	10	10	10				MgI		S.	
4108 R	9	10					SrBr		S.	
4107·9 R	—	—	—			5	CO ₂			e.
4102·3 V	—			9	9		C ₂	Deslandres-		
								d'Azambuja	S.	c.
4101·2 R			5				HfO		S.	
4095·4 R	—			10			O ₂	Schumann-Runge		
4094·5 R			10				AgO			
4094·2 R					10		NiCl			hf.
4093 V	—	—			1		C ₂	High Pressure	D.	c.
*4087·4 R				8	8		SiN			N.
4085·9 V	—				10		TiCl	Violet		
4084·3 R			10				CaO		S.	
4082·4 R	—	—	—			9	O ₂ ⁺	2nd Negative		He.
4070·7 R	—	—	—			.5	CO ₂			e.
4070·7 R				10			SnBr			
4068·1 V	—			6	6		C ₂	Deslandres-		
								d'Azambuja		c.
*4066·3 R				5	5		AlH			
4061·5 R					8		NiCl			hf.
4060 M	—			10			TiCl	Violet		
*4059·4 V	—	—			8		N ₂	2nd Positive	CT.	S.
4053 R	10	10					SrBr		S.	
*4050·7 R				8	8		SiN			N.
4048·9 R	—	—	—			5	CO ₂			e.
4045·6 R	2	9	8		8		S ₂		wv.	
4045·6 M	—				9		TiCl	Violet		
4041·8 V	—			3	3		C ₂	Deslandres-		
								d'Azambuja		c.
4041·7 R	—	—	—		7		Cl ₂ ⁺			hf.
4035·5 R			7				BO	α	CD.	N.
4033·0 R	—	—	—		7		Cl ₂ ⁺			hf.
*4027·8 R	—	—	—		6		NO	β	D.	N.
4025·3 R		3		3	3		CH			
4020·6 R	—			9			O ₂	Schumann-Runge		
4019·7 R	—	—	—			9	CO ⁺	Comet-tail		
4017·7 R	—	—	—			9	CO ⁺	Comet-tail		
4017 V					10		HgH			
*4016·8 R				6	6		SiN			N.
4015·0 R			5				BO	α	CD.	N.
4014·8 R					8		CP	A.		A.
4006·2 R			8				TaO			

THE IDENTIFICATION OF MOLECULAR SPECTRA

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
4005.4 R				5			CuH		
3999.6 R	—	—	—			9	CO ⁺	Comet-tail	
*3998.4 V	—	—	—			9	N ₂	2nd Positive	CT.
3997.3 R	—	—	—			9	CO ⁺	Comet-tail	
3994.7 R	—	—	—		4		SiN		N.
3989.1 R	—	—	—	—	5		He ₂		D. c.
3987.9 R	—	—	9				SbO		
*3985.8 R	—	—		5	5		SiN		N.
*3984.6 R	—	—	1		1		CN	Cyanogen Violet "Tail"	N.
3973.5 V	—	—	—			9	CO ⁺	Baldet-Johnson	wr. He.
3972.8 R	—	—	—	10			AuH		
3970.1 R	—	—	6				HfO		S.
*3968.5 M	10	—	—	—	—	—	Ca ⁺	Scattered sunlight	
3962.1 R	—	—	—				CH ⁺		
3961.6 R	10	—	6				SrCl		S.
3960.9 R	—	—	—			7	CO ₂		e.
3960.2 R	—	—	—			8	TlBr.		
3959.6 M	—	10	—				CH ₂ O	"Cool Flame"	f. t.
3957.0 V	—	—	—			7	CO ⁺	Baldet-Johnson	D. He.
3955.0 R	9	—	—				PbO	C.	
3954.4 R	—	—	—				CH ⁺		He.
3951 R	6	10	—				CaBr		S.
*3949.8 R	—	—	—	4	4		SiN		N.
3945.2 R	—	—	—		10		TlBr		
*3944.7 R	—	—	2		2		CN	Cyanogen Violet "Tail"	N.
*3943.0 V	—	—	—		8		N ₂	2nd Positive	CT.
3942.9 R	—	10	—		10		SeO		
3940.3 R	—	—	—		5		N ₂	Vegard-Kaplan	e.
3938.9 R	3	9	8		8		S ₂		wv.
3937.1 R	10	—	6				SrCl		S.
*3933.7 M	10	—	—	—	—	—	Ca ⁺	Scattered sunlight	
3933.7 R	—	—	—		8		TlBr		
3930.7 R	—	8	—		8		SeO		D.
3917 R	6	10	—				CaBr		S.
*3914.4 V	—	—	—			10	N ₂ ⁺	1st Negative	S. He.
3914.3 R	—	—	10				BiCl	Ultra-Violet	
3912.3 R	—	—	—	9			O ₂	Schumann-Runge	
*3911.8 R	—	—	—	4	4		SiN		N.
*3909.5 R	—	—	3		3		CN	Cyanogen Violet "Tail"	N.
3900.2 R	—	—	9				BiCl	Ultra-Violet	
3896.4 R	—	—	8				TaO		
3896 M	10	—	—				TlI		
3893 R	—	—	—		5		OH ⁺		hf.
3893.1 V	—	—	—		7		CO	Herzberg	
3889.3 R	—	—	10				GaO		S.
3889.2 R	—	—	—		5		N ₂	Vegard-Kaplan	e.

TABLE OF PERSISTENT BAND HEADS

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
*3889-0 R		4		4	4		CH		
*3884-3 V	—	—	—			3	N ₂ ⁺	1st Negative	He.
*3883-4 V		10	10		10		CN	Cyanogen Violet	S. N.
3880-5 V	10	10	10				MgBr		S.
3878-6 V		3	3				BaF		S.
3877-8 R	10						PbO	C.	
*3871-4 V		8	9		9		CN	Cyanogen Violet	N.
3871-1 R		5			5		CH		
3870-5 R	—	—	—			7	CO ₂		e.
*3868-3 R	—	—	—		6		NO	β	D. N.
3866-0 V	8				8		MnBr		hf.
3865-1 R	6				8		SnSe		
3864-1 V	10	10	10				MgBr		S.
*3861-9 V		6	8		8		CN	Cyanogen Violet	N.
3860-5 V				5			MgCl		S.
3859-5 R	—	—	—			9	O ₂ ⁺	2nd Negative	He.
*3857-9 V	—	—	—			4	N ₂ ⁺	1st Negative	He.
3855-5 M	—	9					CH ₂ O	"Cool Flame"	f. t.
*3854-7 V		4	6		6		CN	Cyanogen Violet	N.
3854-4 R			6				BiCl	Ultra-Violet	
3853-2 R	—	—	—			4	CO ₂		e.
3852-2 V	—			10	10		C ₂	Deslandres- d'Azambuja	S. c.
3847-0 R			9				BO	α	CD. N.
3845-2 V	4	4	4				MgCl		CD. S.
3844 M	4						HNO ₂ ?		
3840-6 R	—	—	—	10			O ₂	Schumann-Runge	
3838-8 R	—	—	—			6	CO ₂		e.
3837-1 R	4	9	8		8		S ₂		wv.
3836 M	10						TII		
3834-6 V	10				10		MnBr		S. hf.
3832-9 R	—	—	6	6			SiO ⁺		
3830-5 R	—	—	—			9	O ₂ ⁺	2nd Negative	He.
3828-0 R			6				BO	α	CD. N.
3825-6 V	—	—	—	6	6		C ₂	Deslandres- d'Azambuja	c.
3825 R	3	—	—	—	—	—	O ₂	Liquid	
3818-8 R	8				10		TeO		
3817-7 R	9				9		SnSe		
3815-6 R		10			10		SeO		
*3814-0 R				2	2		SiN		N.
3811-8 R		5			5		SO		
3809-9 V	10	10	10				BaF		S.
3808 M	10						TII		
3807-3 R		8			8		SeO		D.
*3804-9 V	—	—	—		10		N ₂	2nd Positive	CT. S.
3803-2 R					6		BN		He.
3795-8 R	—	—	—			8	CO ⁺	Comet-tail	
3792 R	—	—	—			10	BH ⁺		

THE IDENTIFICATION OF MOLECULAR SPECTRA

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .		System.	App.	Occ.
*3788·5 R	—	—			10		NO	β	D.	N.
3778·9 V	10	10		10			MgCl		CD. S.	
3778·5 V			9				GaO		S.	
3777·9 R					8		CP	A.		A.
3777·8 R	—	—	—			8	CO ⁺	Comet-tail		
3774·4 R		8	8				CaCl		CD. S.	
3774·0 R			9				SbO			
3772·1 V	8				8		MnBr			hf.
3770·9 R	5				9		SnSe			
3770·4 V	8				8		MnCl		S.	hf.
3768·1 R	—	—	—			10	BH ⁺			
3763·5 R		8	8				CaCl		CD. S.	
3760·3 R						10	HBr ⁺			
3758·6 R					10		SnCl		S.	
*3755·4 V	—	—			10		N ₂	2nd Positive	CT.	
3753·2 R			7				CaO			
3747·2 R			8				TaO			
3741·7 R	—			9			O ₂	Schumann-Runge		
3739·8 R	5	9	8		8		S ₂		wv.	
3739·2 R	5				10		SnSe			
3733·9 R	—	—	—			9	O ₂ ⁺	2nd Negative		He.
3731·9 V	7		4				MgO ?			
3730·5 R		5					CHO ?	Ethylene flame		
3725·9 V	8		4				MgO ?			
3724·9 V	—	—	—			8	CO ⁺	Baldet-Johnson	wr.	He.
3721·4 V	10		5				MgO ?			
3720·5 V	10				10		MnBr			hf.
3716·8 V	10				10		MnCl		CD. S.	hf.
3712·4 R			2				SrF		S.	
3711·2 V	—	—	—			9	CO ⁺	Baldet-Johnson	D.	He.
3711·0 V	4	4	4				MgCl		CD. S.	
*3710·5 V	—	—			8		N ₂	2nd Positive	CT.	
3710·0 R	8				10		TeO			
3706·6 R	—	—	—			9	O ₂ ⁺	2nd Negative		He.
3706·3 M	—	10					CH ₂ O	"Cool Flame"		f. t.
3697·7 R		4					CHO ?	Ethylene flame		
3695·0 R			10				SbO			
3694·1 R	5				9		SnSe			
3693·8 R	—	—	—			5	BH			
3691·8 R	—	—	—			7	CO ₂			e.
3690·2 R		7			7		SeO		D.	
3685·8 V			5				MgF		CD. S.	
3681 M	10						HNO ₂ ?			
3680·9 V	—	—	—		4		CO	Herzberg		
3677·8 R			8				BO	α	CD.	N.
3676·2 R		7			7		SO			
3675 V			8				CrH			
3674·1 R	—	—	—			6	CO ₂			e.
3672·7 R	—	—	—	9			O ₂	Schumann-Runge		
3665·0 R	—	—	—		5		He ₂		D.	c.

TABLE OF PERSISTENT BAND HEADS

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.	
3664.0 R	5				9		SnSe			
3662.4 R	—	—				5	BH			
3661.6 R	—	—	—			6	CO ₂	S.	e.	
3661.3 V					5		MnCl	CD. S.		
3661.3 R	8				8		TeO			
3656.6 R			7				CaO	S.		
3654.3 R			2				HfO	S.		
3651.5 R				9			AuH			
*3647.2 R	—	—			4		NO	β	D.	N.
3646.3 R			3				SrF	S.		
3645.0 R	5	8	8		8		S ₂	wv.		
3632.3 V				10		10	AlH ⁺			
3629.8 R	—	—	—			9	O ₂ ⁺	2nd Negative	He.	
*3628.9 R			1		1		CN	Cyanogen Violet "Tail"	N.	
3628 R	3	—	—	—	—	—	O ₂	Liquid		
3628 R		1		1	1		CH			
3627.2 R					4		NH		N.	
3625.7 R			8				TaO			
3621.7 R			9				SbO			
3621.0 R	—	—	—			7	CO ₂		e.	
3620.7 V			4				AgO	S.		
3617.3 R					10		SiTe			
*3614.9 V			4				LaO	S.		
3612.4 R					10		CP	A.	A.	
*3612.4 R	—	—	—			1	N ₂ ⁺	1st Negative	He.	
3611.9 V				10		10	AlH ⁺			
3609.6 R					2		NH		N.	
3607.3 V	—			8	8		C ₂	Deslandres- d'Azambuja	S.	c.
3607.0 R	8				8		TeO			
3603.7 R	—	—	—			8	O ₂ ⁺	2nd Negative	He.	
3603.0 R					5		N ₂	Vegard-Kaplan	e.	
*3603.0 R			3		3		CN	Cyanogen Violet "Tail"	N.	
3600.8 R	—	—	—			6	CO ⁺	Comet-tail		
3599.2 R					10		BN		He.	
3599.2 V	7				7		InCl		hf.	
3594.2 V			10				MgF		CD. S.	
3594.1 R	10						ClO ₂			
3593.2 R					10		PbSe	D.		
3592.9 V	—			7	7		C ₂	Deslandres- d'Azambuja	c.	
3591.6 R	—	—				10	HCl ⁺			
3591.6 R	5				10		SnSe			
*3590.4 V		7	8		8		CN	Cyanogen Violet	S.	N.
3588.6 R		8					CHO?	Ethylene flame		
3587.6 V	—			7	7		C ₂	Deslandres- d'Azambuja	c.	
3587.2 R	5	8	8		8		S ₂			

THE IDENTIFICATION OF MOLECULAR SPECTRA

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
*3585.9 V		6	7		7		CN	Cyanogen Violet	N.
3585.4 R	7		8				SnO		
3584.2 R	—	—	—			6	CO ⁺	Comet-tail	
*3583.9 V		5	6		6		CN	Cyanogen Violet	N.
*3582.1 V	—	—	—			6	N ₂ ⁺	1st Negative	He.
3578.9 R		7			7		SeO		D.
*3576.9 V	—	—			10		N ₂	2nd Positive	CT. S.
*3572.4 R	—	—			10		NO	β	D.
3567.0 R			10				BeCl		S.
3565 R	—	—	—		10		OH ⁺		hf.
3564.0 R			9				CaO		S.
3563.5 R	5				9		SnSe		
3562.2 R	—	—	—			8	CO ₂		e.
3560.6 R	8				8		TeO		
3558.4 V			8				AgO		S.
3557.8 R					10		PbSe	D.	
3556.1 R					10		SiTe		
3553.5 V			10				AgO		
3551.4 R	—	—	—			8	CO ₂		e.
3549.4 M					10		Br ₂		
3549.0 V	10						BaF		
3548.7 R		6			6		SO		
3545.9 R	—	—	—			9	CO ₂		e.
3541 M	10						HNO ₂ ?		
*3536.7 V	—	—			8		N ₂	2nd Positive	CT.
*3535.0 R				4	4		SiN		D.
3533.8 R	—	—	—			7	CO ₂		N.
3529.8 V	10						SrF	D.	S.
3525.5 R			7				BO	α	CD.
3517.7 R	—	—	—			9	O ₂ ⁺	2nd Negative	N.
3516.1 R	—				8		O ₂	Schumann-Runge	He.
3516 R					5		AgH		
3514.3 R						10	SiTe		
3511.7 V	—	—	—			7	CO ⁺	Baldet-Johnson	wr.
3511.4 R	10						ClO ₂		
3510.8 R	—	—	—			6	CO ₂		e.
3508.2 R					8		CP	A.	A.
3507.3 R	—	—	—			10	HCl ⁺		
3503.8 R			10				SrO		
3503.4 V			4				MgF		CD. S.
*3503.2 R	—	—	—			6	CO ₂		e.
3502.7 R		8					CHO?	Ethylene flame	
3500 V					5		HgH		
3500.4 V	—	—	—			3	CO ⁺	Baldet-Johnson	D.
3500.3 R	5	8	8		8		S ₂		He.
3499.0 V	10				10		InCl		hf.
3494.2 R	—	—	—			8	O ₂ ⁺	2nd Negative	He.
3493.5 V			4				AgO		S.
*3493.3 V	—	—	—		6		CO	3rd Positive	F.
3487.8 R					10		SnCl		S.

TABLE OF PERSISTENT BAND HEADS

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
3485.7 R	8	10	10				PbO D.		
3484.5 R	9	10	10				SnO	S.	
3475.3 R	8				6		TlBr		
3475.0 R			10				CaO	S.	
3473.1 R		6			6		SeO	D.	
3472.5 R		5					CHO ? Ethylene flame		
3463.8 R	8				7		TeO		
3463.6 R	8						TlBr		
3459.2 R					10		CP A.		A.
3452.4 R	9				9		TlBr		
3449.2 R			2				CaF	S.	
3445.2 R			6				SrO		
3441.6 R			6				BO β		N.
3439.7 R					7		BN		He.
3434.0 R	10						ClO ₂		
3429.6 R	10				10		TlBr		
*3428.1 R		4		4	4		OH		DCD.
3425 V	2	10			10		I ₂		
3424.6 R					4		N ₂	Vegard-Kaplan	
3422.2 R	8				7		TeO		
3421.2 R	—	—	—			9	O ₂ ⁺	2nd Negative	He.
3420.5 R	—	—	—			10	HBr ⁺		
3419.6 R					10		PH		
3418.2 R	9				4		TlBr		
3417 M	8						HNO ₂ ?		
3416.1 V					7		FeCl		hf.
3415.1 V					10		BH		He.
3409.1 R			7				CaO	S.	
3402.4 R			10				SbO		
3401.9 R	8	8	8				PbO D.		
3399.7 V	—			5	5		C ₂	Deslandres-d'Azambuja	S.
3398.1 V	—			5	5		C ₂	Deslandres-d'Azambuja	S.
3397.8 R	—	—	—			9	O ₂ ⁺	2nd Negative	c.
3396.4 V					5		BH		He.
3395.3 V	10						BaF		He.
3389.8 R			6				SrO		
3389 M	4						CH ₂ O	Formaldehyde	
3388.3 R	8	7	7				SnO	S.	
3387.6 R			6				BO α	CD.	N.
3384.4 V					10		CdI		
3383.1 R		6			6		SO		
*3381.3 R	—	—	—			1	N ₂ ⁺	1st Negative	He.
*3377.5 R	—	—	—			10	CO ₂		e.
3377.4 R		10					CHO ? Ethylene flame		
*3376.4 R	—	—			10		NO β	D.	N.
3374.1 M	3	—	—				O ₃		
*3371.3 V	—	—	—		10		N ₂	2nd Positive	CT: S.

THE IDENTIFICATION OF MOLECULAR SPECTRA

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
3371.1 R			2				CaF	S.	
*3370 M		10		10	10		NH	L.	
*3370.0 R	—	—	—			10	CO ₂	S.	e.
3369.6 R	—			8			O ₂	Schumann-Runge	
3369.4 R	6	7	8		8		S ₂		
3363.5 R					10		CP	A.	A.
3363 M					10		SiF	η	
3360.5 R	10						ClO ₂		
*3360 M		9		9	9		NH		L.
3359.0 R		5					CHO ?	Ethylene flame	
3353.6 R	10						Li ₂		
3348.0 R	—	—	—	—	3		He ₂		D.
3346 M					10		SiF	η	c.
3338.5 M	4	—	—		8		O ₃		
3336.6 M					10		Br ₂		
3336.5 R					10		GeSe		
3332 R					5		OH ⁺		
3330 R				10			AgH		
3323.4 R	10	8	8				SnO		
3315.6 R	9						Li ₂		
3311.9 R		8	8		8		PO	β	
3311.5 M	5	—	—		6		O ₃		
3310.0 R	10						CaF		
*3308.0 V	—	—	—			2	N ₂ ⁺	1st Negative	S.
3306.7 R					9		GeSe		He.
*3305.7 V	—	—	—		7		CO	3rd Positive	F.
3305.4 R			8				BO	β	N.
*3299.7 R	6				7		TiCl		wv.
3299.2 R		10					CHO ?	Ethylene flame	
*3298.7 V	—	—	—			2	N ₂ ⁺	1st Negative	He.
3297.6 R	3				7		SiS		
3296.4 R		8	8		8		PO	β	
3292.0 R					5		GeSe		
3290.4 V					7		SnBr		
*3289.6 R	6				8		TiCl		wv.
3288 R	6						CH ₂ O	Formaldehyde	
3284.3 R	—	—	—			5	CO ₂		e.
3283.4 R					8		B ₂		N. He.
3279.8 M	8	—	—		3		O ₃		
3277.2 R		10	10		10		AsO		CD.
3274.8 M	8						CS ₂		
3273.7 R					6		CP	A.	A.
3272.8 R					10		B ₂		N. He.
3271.0 R		10			10		SO		
3270.5 V			10		10		PO	β	
*3270.0 R	7				7		TiCl		wv.
3269.9 R	—	—	—			7	CO ₂		e.
3268.9 R		8	8		8		PO	β	

TABLE OF PERSISTENT BAND HEADS

29

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
3264·6 R	—	—	—			7	CO ₂		e.
*3263·6 R	8				2		TiCl		
3263·0 R					9		GeSe		
3262·4 R					10		SiSe		
3260 M	7						CH ₂ O	Formaldehyde	
*3259·9 R	3				8		TiCl		wv.
3256·9 R			9				BO	β	N.
3255·5 M	5	—	—				O ₃		
3255·3 V			10		10		PO	β	
3254·8 V					5		BF		F. hf.
3253·9 R	—	—	—			8	CO ₂		e.
3253·4 R			8		8		PO	β	
*3253·4 R	—	—	—			5	NH		
3253·1 R	10						Li ₂	Ultra-violet	
3253 V	—	—	—		3		CO	Knauss	r.
3251·7 R	10				8		AgI		hf.
*3250·8 R	8				7		TiCl		wv.
3249·7 M	8	—	—				O ₃		
*3246·9 R	—	—	—			8	CO ₂		S. e.
3246·3 R		10	10		10		PO	β	
3245·4 V	10						CaF	D.	
*3242·1 V	—	—	—		6		CO	5B	F.
*3240·6 R	8				9		TiCl		
*3240·1 R	—	—	—		2		NH		N.
3236·6 R	10	10					SH		
3235 M	8						CS ₂		
3234·4 V					7		SnCl		
3232·5 R	—			7			O ₂	Schumann-Runge	
3231·2 R	—	—	—			9	O ₂ ⁺	2nd Negative	He.
*3230·4 R	9				10		TiCl		
3230·3 R	9				8		AgI		hf.
3227·2 M	10	—	—				O ₃		
3221·8 R	4				8		SiS		
3221·5 M	10	—	—				O ₃		
*3220·9 R	10				10		TiCl		S.
3210·8 R	—	—	—			9	O ₂ ⁺	2nd Negative	He.
3210·0 R	10						AgI		
3209·3 R			7				BO	β	N.
3208·9 R	5				8		AgI		hf.
3207·8 R		6	7		7		AsO		CD.
3204·4 M	9						CS ₂		
3203·0 R					10		SiSe		
3201·0 M	8	—	—				O ₃		
3200·8 R	8				9		AgCl		S. hf. f.
3199·5 R	10						AgBr		
*3198·0 R	—	—	—		10		NO	β	D. N.
3197·8 V					7		SnCl		
3197·5 R					5		N ₂	Vegard-Kaplan	
3196·8 R	6				2		AgI		hf.
3194·8 M	6	—	—				O ₃		

THE IDENTIFICATION OF MOLECULAR SPECTRA

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
*3193-4 R	7				1		TiCl		
3190-2 R					8		CP	A.	A.
3189-5 M	10						CS ₂		
3185-4 R	7				4		AgI		hf.
*3182-6 R	6				2		TiCl	S.	
3179 R				5			AgH		
3177-0 M	8	—	—				O ₃		
3176-6 V					10		CdBr		
3176-5 R					3		B ₂		N. He.
3176-5 V	10						BaF		
3170-6 R		9	9		9		AsO	CD.	
3167-6 V	10						SrF	E.	S.
3166-2 R	10				10		AgCl		S.
3164-8 R		10			10		SO		hf. f.
3164 R	9						CH ₂ O	Formaldehyde	
3163-0 V	5						BaF		
*3159-3 V	—	—	—		9		N ₂	2nd Positive	CT. S.
3156-1 M	8	—	—				O ₃		
3145-3 R					9		SiSe		
3144-0 M	8						CS ₂		
3143 M	8						CH ₂ O	Formaldehyde	
3143-4 R		1			1		CH		L.
3141-2 V	?						SnF		
3139-7 R	10				9		AgCl		S.
3138 V	—	—	—		4		CO	Knauss	hf. f. r.
3137-4 M	10	—	—				O ₃		
*3136-0 V	—	—	—		8		N ₂	2nd Positive	CT.
*3134-4 V	—	—	—		8		CO	3rd Positive	F.
*3132-9 R	—	—	—		6		CO ₂		S.
3127-7 R	4				8		SiS		S.
3122-1 V					9		BF		F.
3118-6 V	—	—	—		3		N ₂	Gaydon-Herman	hf. c.
3114-3 M	8	—	—				O ₃		
3107-5 R	—	—	—			2	CO ⁺	1st Negative	He.
3106-4 R					9		SiSe		
3105-6 R		6	7		7		AsO		CD.
3105-0 M	5	—	—		6		O ₃		
3103-9 R	—	—	—	6			O ₂	Schumann-Runge	
3103-0 R	6				6		GeS	A.	
3098-9 V					3		BH		He.
3091-5 R	9	8	9		9		S ₂		
3089-5 M	8	—	—		10		O ₃		
3088-6 R			9				BO	β	N.
*3079-9 V	—	—	—		5		CO	5B	F.
3077 V					7		COS ?		
3067-5 R	8				8		GeS	A.	
3064-1 R		10			10		SO		
3064-0 R	—	—	—			3	CO ⁺	1st Negative	He.
*3063-6 R	10	10		10	10		OH ⁺		DCD. wv.
3062-8 R	—	—	—			9	O ₂ ⁺	2nd Negative	He.

TABLE OF PERSISTENT BAND HEADS

31

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
3057.9 R	6				9		SiS	S.	
3048.9 R	5				5		GeS A.		
3047.7 V					9		SiBr		
3043.6 V					7		SnBr		
3043.6 R			9				BO β		N.
3043.6 R	—	—	—			9	O ₂ ⁺ 2nd Negative		He.
3043 V					10		COS ?		
3042.6 R					3		NH		N.
*3042 R	7	—	—		—		SO ₂		
3041.5 V	8						SrF F.	S.	
3035.2 R					1		NH		N.
*3034.9 R	—	—			10		NO β	D.	N.
3033 R	7						CH ₂ O Formaldehyde	wv.	
3028 V	—	—	—		3		CO Knauss		r.
3024.6 R	9	7	8		8		S ₂		
3023.0 R	—	—	—			2	CO ⁺ 1st Negative		He.
*3021 R	9	—	—		—		SO ₂		
3014.8 R		8					CHO ? Ethylene flame		
3014.4 R	7				7		GeS A.		
3009 V					10		COS ?		
3009.6 R			9				BeF	CD.	
3008.8 V					10		SiBr	wr.	
*3008.8 V	0	4	4		4		NO γ	DCD.	
*3000 R	10	—	—		—		SO ₂		
2999.7 R			7				BO β		N.
2990.8 R	7				10		SiS	S.	
2990.4 R	0			10			SnO Loomis & Watson		
2989.5 R	9	7	8		8		S ₂	wv.	
2988.8 V					8		SiCl		
2987.8 V	10						SrF F.	S.	
2987.5 R	—	—	—			9	O ₂ ⁺ 2nd Negative		He.
2985.7 R					9		SbN	CD. S.	
2984.2 R	—	—	—			2	CO ⁺ 1st Negative		He.
*2979 R	9	—	—		—		SO ₂		
*2977.4 V	—	—	—		9		CO 3rd Positive	F.	
*2976.8 V	—	—			6		N ₂ 2nd Positive	CT. S.	
2976.2 R	1				10		ZnCl		hf.
2973.4 V					8		SnCl		
2970.4 V					8		SiCl		
2970.0 R	—	—	—			8	O ₂ ⁺ 2nd Negative		He.
2967.1 V					6		SiF β	D.	
2967.0 V	—	—			3		N ₂ Gaydon-Herman		c.
*2960.2 R	10	—	—		—		SO ₂		
2958.7 V					7		SiBr		
2956 V	8						ZnCl ?		
2954.2 M					10		BBr		hf.
2954.0 R	10	7	8		8		S ₂	wv.	
2948.2 R		7					CHO ? Ethylene flame		
2948.1 V					10		BBr		
2944.2 R					9		BBr		

THE IDENTIFICATION OF MOLECULAR SPECTRA

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
2943 V					10		COS ?		
*2943·0 R	9	—	—		—		SO ₂		
2942·6 R	5				10		ZnCl	S.	hf.
2942·2 V					8		SiCl		
*2936·7 R	8	—	—		—		SO ₂		
2935·8 V					10		SnCl		
2935·7 R					9		N ₂	Vegard-Kaplan	
2935·7 R					7		BBr	S.	hf.
2934 V	10						ZnCl ?		
2934·9 R			9				BO	β	N.
2931 R	10						CH ₂ O	Formaldehyde	
2927·9 V	?						SnF		
2926·2 V	10						CaF	E.	
2926·1 R	8				10		SiS	S.	
2925·5 R							CdF		
2925 V	—	—	—		2		CO	Knauss	r.
2924·4 V					8		SiCl		
*2923 R	8	—	—		—		SO ₂		
2921·7 R	2			10			SnO	Loomis & Watson	
2920·2 R	10	7	8		8		S ₂	wv.	
2919·8 R	—	—	—			9	O ₂ ⁺	2nd Negative	He.
2912·0 R					7		SbN	CD.	
2911 V					10		COS ?		
*2905·5 R	8	—	—		—		SO ₂		
2904·3 R					10		SbN	CD. S.	
2903·9 V	—	—	—		1		N ₂	4th Positive	F. c.
2901·9 R	—	—	—			8	O ₂ ⁺	2nd Negative	He.
2900·4 M	1	10			10		Br ₂		
*2898·4 R			3		3		SiO		
2898·1 R	—				4		C ₆ H ₆	Benzene	S. t.
2897·2 R	—	—	—			3	CO ⁺	1st Negative	He.
*2896 M	—	—	—		10		CO ₂ ⁺		
2894·4 V					6		SiF	β	D.
2893 R	10						SeO ₂		
2892·3 R	10	7	8		8		S ₂		
2892·2 R			10				BO	β	N.
2890·3 R	—	—	—			8	O ₂ ⁺	2nd Negative	He.
2887·9 R	10	7	8		8		S ₂		
*2886·7 R	9	—	—		—		SO ₂		
*2885·2 R	—	—	—		10		NO	β	D. N.
2883·2 R	7				8		SiS		
*2883 M	—	—	—		10		CO ₂ ⁺		
2882·9 V					8		SiCl		
2881·7 R			10		10		GeO	S.	
2880·6 R							CdF		
2880 V					7		COS ?		
2877·9 R	—	—	—		4		N ₂	Gaydon-Herman	c.
*2875 R		2		2	2		OH		
2873·2 V	10						SrF	G. S.	
2872 R	10						SeO ₂		

TABLE OF PERSISTENT BAND HEADS

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
*2871-6 R			4		4		SiO		
2868-7 R					6		AsN	CD.	
*2867 R	8	—	—		—		SO ₂		
2866-2 R	5						PbO	E.	
2865-8 V					8		SiCl		
2863-7 R	8				8		SiS	S.	
2860-0 R	9	5	7		7		S ₂	wv.	
*2859-5 V	0	6	6		6		NO	γ	DCD.
2858-1 R	—	—	—			4	CO +	1st Negative	He.
2858-0 R		6					CHO ?	Ethylene flame	
2856-8 V					5		CCl		T. wr.
*2852 R	9	—	—		—		SO ₂		
2850-6 R			8				BO	β	N.
2844-5 R					10		CSe		D. hf.
2843-5 V	10				10		TiF	S.	
2839-7 R	—	—	—			10	O ₂ ⁺	2nd Negative	He.
2839 R	9						CH ₂ O	Formaldehyde	wv.
2838-5 R							CdF		
2837-9 R	—				6		C ₆ H ₆	Benzene	t.
*2833-1 V	—	—	—		10		CO	3rd Positive	F.
*2832 R	8	—	—		—		SO ₂		
2829-1 R	9	5	7		7		S ₂	wv.	
2827-4 R		8			8		SO		
✓ 2827-1 V	—	—			4		N ₂	Gaydon-Herman	c.
2826-7 V	8						SrF	G.	S.
2823-7 R	—	—	—			9	O ₂ ⁺	2nd Negative	He.
✓ 2822-7 R	9				9		SiS		S.
2820-8 R	—	—	—			5	CO ⁺	1st Negative	He.
*2819-8 V	—	—			1		N ₂	2nd Positive	CT. S.
2818-3 R					9		AlBr		CD. S. hf.
2818 R	10						SeO ₂		
2814-8 R	5			10			SnO	Loomis & Watson	
2812-3 R	—				7		C ₆ H ₆	Benzene	S. t.
*2811-3 R	9	8		8	8		OH		DCD. wv.
*2810-4 (V)	0	4	5		5		NO	γ	DCD.
*2810-2 R	6						Bi ₂		
2809-9 R			8				BO	β	N.
2809-7 V					10		SiCl		
*2806-3 R			8		8		SiO		
2804-2 R			10		10		GeO	S.	
*2802-6 R		—			4		NO	β	D. N.
2799-7 R					9		CO	4th Positive	
2799 R	10						SeO ₂		
2798-8 R	9	5	7		7		S ₂		*
*2797 R	8	—	—		—		SO ₂		
2797-1 R		5					CHO ?	Ethylene flame	
*2796-9 R	8						Bi ₂		
2796-3 R					9		AlBr		CD. hf.
2796-0 M	—	—			3		N ₂	Gaydon-Herman	c.
2789-8 V					10		CCl	T. wr.	

THE IDENTIFICATION OF MOLECULAR SPECTRA

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App. CD. S.	Occ. hf.
2788·8 R					10		AlBr		hf.
2787 R	7						CH ₂ O	Formaldehyde	
2785·8 R	—	—	—			5	CO ⁺	1st Negative	He.
2784·2 R					10		AsN		CD.
*2783·7 R	6						Bi ₂		
2783·2 R	10				9		SiS		S.
2783 V					9		BCl		S.
*2780·5 R		6	7		7		SiO		
2777·9 V	—	—	—		2		N ₂	4th Positive	F.
2776·7 R	—	—	—			8	O ₂ ⁺	2nd Negative	D.
2769·4 R	9	5	7		7		S ₂		
*2768·9 R	8						Bi ₂		CD. S.
2767·2 R					9		AlBr		hf.
*2763·3 V	0	1	2		2		NO	γ	DCD.
2761·9 R	—	—	—			7	O ₂ ⁺	2nd Negative	He.
2760·6 R					9		N ₂	Vegard-Kaplan	
2756 R	5						CH ₂ O	Formaldehyde	
*2755·0 R		6	6		6		SiO		
*2754·7 R		7	6		7		CS		CD.
2753·4 R			9				BO	β	N.
2752·9 R	—	—	—			6	CO ⁺	1st Negative	He.
2751·2 R	—	—	—		7		C ₆ H ₆	Benzene	t.
2750 V	—	—	—		1		CO	Kaplan	F.
*2747·6 R					9		NO	β	D.
2747 R	5						CH ₂ O	Formaldehyde	N.
2746·1 R	—	—			3		N ₂	Gaydon-Herman	c.
2745·3 R	9				8		SiS		S.
*2744·5 R	7						Bi ₂		
2744·0 R		6			6		SO		
2740 V					?		N ₂	Kaplan 2	
2739·1 R	—				10		C ₆ H ₆	Benzene	S.
2736·5 R	—				8		C ₆ H ₆	Benzene	t.
*2731·6 R	10					6	Bi ₂		He.
2722·3 R	—	—	—				CO ⁺	1st Negative	DCD.
*2722·2 V	1	8	8		8		NO	γ	
2722·2 V					10		BCl		He. hf.
*2720·7 R	8						Bi ₂		He. hf.
2720·0 V					10		BCl		
2719·5 R					7		AsN ₄		CD.
2716·9 R	8			9			SnO	Loomis & Watson	
2716·0 R		5					CHO?	Ethylene flame	S.
2714·2 R					8		BCl		hf.
2713·8 R			10				BO	β	N.
2713·7 R	10				10		TiF		S.
2711·3 V	—	—	—		3		CO	3A.	Fd.
*2710·3 R	6						Bi ₂		
2706·8 V		2	3		3		PO	γ	CD.
2705·3 R	—	—	—			8	O ₂ ⁺	2nd Negative	D.
2699·1 R		4			4		SO		He.
2697·4 R					5		NS	β	

TABLE OF PERSISTENT BAND HEADS

35

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
*2693-7 R		7	9		9		SiO		
*2693-2 R		8	8		8		CS	CD.	
2692-4 V		3	4		4		PO γ	CD.	
2690-8 V		3	4		4		PO γ	CD.	
2689-3 V			5				MgF	S.	
*2685-7 V					7		AlCl		
2683-3 R					4		NS β		
*2683-1 V					7		AlCl		
2681-2 V	—	—			5		N ₂ 5th Positive		c.
2680-0 R					4		NS β		
*2680-0 V	0	3	5		5		NO γ	DCD.	
2678-6 R					9		C ₆ H ₆ Benzene		t.
*2677-0 R		6	6		6		CS	CD.	
2676-7 V		3	4		4		PO γ	CD.	
2675-3 R			8				BO β		N.
2672-4 R	—	—	—			7	CO ⁺ 1st Negative		He.
*2672-2 R					7		NO β	D.	N.
2671-7 M	—	—			5		N ₂ Gaydon-Herman		c.
*2669-0 R		8	9		9		SiO		
*2667-4 R	1				10		C ₆ H ₆ Benzene	S.	t.
*2665-3 V	—	—	—		8		CO 5B	F.	
2664-8 R		5			5		SO		
2662-9 V		2	3		3		PO γ	CD.	
*2662-6 R		10	9		10		CS	CD.	
2660-5 V	—	—	—		5		N ₂ 4th Positive	F.	c.
2659-8 R					8		BCl	S.	hf.
2659-1 V	10						CaF F.		
2658-8 R		4					CHO? Ethylene flame		
2657-4 R	3						GeS B.		
2653 R	10						SeO ₂		
*2649-7 V					5		AlCl		
*2647-5 V					7		AlCl		
*2644-8 R		4	4		4		SiO		
2638-8 R	—	—	—			8	CO ⁺ 1st Negative		He.
2636-3 V		6	7		7		PO γ	CD. S.	
2636-2 V	—	—	—		5		N ₂ Kaplan 2		c.
2632-7 R	—	—	—			7	O ₂ ⁺ 2nd Negative	D.	He.
2630 V	—	—	—		2		CO Kaplan		
*2623-5 R					6		AlCl		
2623-4 V		6	7		7		PO γ	CD.	
2622-2 R		2			3		SO		
2620-5 V		7	8		8		PO	CD.	
*2620-5 R		—			6		NO β	D.	N.
*2620-0 R					5		AlCl		
2618-0 R	2						GeS B.		
*2617-0 R					5		AlCl		
2615-0 R	3						GeS B.		
2614-6 R					4		NS β		
*2614-4 R					10		AlCl		
2613-6 R					8		C ₆ H ₆ Benzene		t.

THE IDENTIFICATION OF MOLECULAR SPECTRA

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
*2610.2 R					6		AlCl		
*2608.5 R		2		3	3		OH	DCD. wv.	
2608.0 V		6	7		7		PO	CD.	
2607.2 R	—	—	—			8	CO ⁺	1st Negative	He.
*2605.9 R		9	9		10		CS	CD.	
2605.0 R					9		PN	CD. S.	
2603.8 R					10		N ₂	Vegard-Kaplan	
2603.3 R	—	—			4		N ₂	Gaydon-Herman	L. c.
*2602.6 R	2				9		C ₆ H ₆	Benzene	S. t.
*2602.1 R		—			6		NO	β	D. N.
2597.1 R					6		NS	β	
2597.0 R	2						GeS	B.	
2596.9 V	—	—	—		4		CO	3A.	Fd.
*2595.7 V	3	9	9		9		NO	γ	CD.
2595.5 V	?						SnF		CD.
2591 M	5	—	—				O ₂	Herzberg	T.
*2589.6 R		6	6		6		CS		CD.
2589.0 R		2			2		SO		
*2589.0 R	9						C ₆ H ₆	Benzene	S.
2588.0 R			8				BO	β	N.
*2587.5 V	3	9	9		9		NO	γ	CD.
*2587.1 R		8	5		5		SiO		
2586.5 V	—	—			7		N ₂	5th Positive	c.
2584.8 R					5		NS	β	
2581.0 R	—	—	—			9	O ₂ ⁺	2nd Negative	D. He.
2577.7 R	—	—	—			10	CO ⁺	1st Negative	He.
*2575.6 R		10	10		10		CS		CD.
2575.3 R					8		CO	Cameron	F. He. r.
2575 R					6		CO?	Kaplan	
2570.9 V	9	9	9		9		AsO		CD. S.
2569.6 M	—	—			4		N ₂	Gaydon-Herman	L. c.
2565.2 R			8				SbO		S.
*2563.8 R		8	5		5		SiO		S.
*2557.3 V	—	—				1	NH		
2555.0 V		9	10		10		PO	γ	CD. S.
2553 M	7	—	—				O ₂	Herzberg	T.
2553.3 R					6		CO	Cameron	F. He. r.
*2551.8 R		—			5		NO	β	D. N.
2551.4 R			9				BO	β	N.
2550.7 V	—	—	—		8		N ₂	4th Positive	F. c.
2550.3 R	—	—	—			7	CO ⁺	1st Negative	He.
2548.6 R		1			2		SO		
2545.5 R	—	—	—			8	O ₂ ⁺	2nd Negative	He.
2543.9 V		6	7		7		PO	γ	CD.
2540.4 V		6	10		10		PO	γ	CD.
2540.1 R					2		NS	β	
2539.2 V					7		SiF	γ	D.
*2538.5 R		4	5		6		CS		CD.
2536.6 V	—	—			5		N ₂	Kaplan 2	c.
2535.0 V					10		HgCl		hf.

TABLE OF PERSISTENT BAND HEADS

	Ab.	F.	A(a).	A(r).	D+.	D-.	System.	App.	Occ.
2532.8 R	—	—	—			7	O ₂ ⁺ 2nd Negative		He.
*2530.2 V	—	—	—			3	NH	L.	
2529.4 V		6	7		7		PO γ	CD.	
*2528.6 R	10						C ₆ H ₆ Benzene	S.	
*2523.2 R		6	6		7		CS	CD.	
2518.5 R						8	NS β		
2518.2 R					10		PN	CD. S.	
2518 M	9	—	—				O ₂ Herzberg	T.	
2518 V	—	—	—		2		CO Kaplan	F.	H.
2516.5 V					10		HgCl		hf.
2513.2 R			10				SbO	S.	
2510.9 R					6		CO Cameron	F.	He. r.
*2509.9 R		3	4		4		SiO		
2509.8 R					6		N ₂ Vegard-Kaplan		
2506.7 R					8		NS β		
2504.7 V	10	8	8		8		AsO	CD. S.	
2504.6 R	—	—	—			10	CO ⁺ 1st Negative		He.
2496.8 M	—	—	—		5		N ₂ Gaydon-Herman	L.	c.
2495.4 V					10		HgCl		hf.
*2493.7 R		2	4		6		CS	CD.	
2491.4 R	6						NO ₂		
2491 R					4		CO Cameron	F.	He. r.
2490.6 R	10				10		GaCl		hf.
2489.9 V	—	—	—		5		CO 3A.	Fd.	
2489 M	10	—	—				O ₂ Herzberg	T.	
2488.3 R	—	—	—			6	O ₂ ⁺ 2nd Negative	D.	He.
*2487.8 R	—	—	—		7		NO β	D.	N.
*2486.8 R		10	7		6		SiO	S.	
*2478.7 V	5	10	10		10		NO γ	CD.	
2477.9 V		9	10		10		PO γ	CD. S.	
*2477.0 R		2	3		4		CS	CD.	
2476.1 R					10		Hg ₂ ⁺		hf.
2474.2 R	—	—	—			10	CO ⁺ 1st Negative		He.
*2471.1 V	5	10	10		10		NO γ	CD.	
*2471.0 R	9						C ₆ H ₆ Benzene	S.	
2468.3 V		5	6		6		PO γ	CD.	
2467.8 V					6		SiCl		
2465 M	9	—	—				O ₂ Herzberg	T.	
2464.2 V		9	10		10		PO γ	CD.	
2463.2 R					10		CO 4th Positive		
2461.6 R					9		N ₂ Vegard-Kaplan		
2460.7 R					7		NS β		
*2460.2 R		3	4		5		CS	CD.	
2459.6 R			8				SbO	S.	
2459.3 R	5						NO ₂		
*2459.0 R		4	3		3		SiO		
2456.0 V					7		SiCl		
2454.6 V		5	6		6		PO γ	CD.	
2453.0 V					5		NS γ	CD.	
2451.8 R					6		CO Cameron	F.	He. r.

THE IDENTIFICATION OF MOLECULAR SPECTRA

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App. CD. S.	Occ.
2451.1 R					8		PN		
2448.7 R					6		NS	β	
2448.0 V	—	—	—		10		N ₂	4th Positive	F.
2445.8 R	—	—	—			10	CO ⁺	1st Negative	CD.
*2444.8 R		2	2		3		CS		
2440 M	7	—	—				O ₂	Herzberg	
2439.7 V					4		NS	γ	CD.
2438.5 V	8	3	4		4		AsO		CD. S.
2437.1 R			10				BO	β	
*2436.3 R			3		3		SiO		N.
2433.9 R					9		CO	4th Positive	
2429.2 V					10		MgH		
*2427.8 R		—			7		NO	β	D.
2424.1 V					10		MgH		
2419.4 R	—	—	—			8	CO ⁺	1st Negative	He.
2419 R	10						NO ₂		
*2415.9 R	5						C ₆ H ₆	Benzene	S.
*2413.8 R		8	7		7		SiO		S.
2411.7 V	—	—			7		N ₂	5th Positive	F.
2409.2 R					6		CO	Cameron	He. r.
2406.0 R					4		NS	β	
2398.5 R			10				BO	β	N.
2398.3 M	10						CHOOH		
2397.1 V	—	—			5		N ₂	Gaydon-Herman	L.
2396.3 V		7	8		8		PO	γ	CD. S.
2394.4 R					4		NS	β	
2392.6 R	—	—	—			3	O ₂ ⁺	2nd Negative	D.
2391.6 V	—	—	—		5		N ₂	Herman-Kaplan	
2389.7 V	—	—	—		5		CO	3A.	Fd.
2388.8 R					6		CO	Cameron	F.
*2387.9 R		3	5		5		SiO		
2387.9 V		6	7		7		PO	γ	CD.
2383.6 V					10		NS	γ	CD.
2383.5 V		7	8		8		PO	γ	CD.
2381.7 V					3		N ₂	Kaplan 1	c.
2377.5 R					7		N ₂	Vegard-Kaplan	
2375.2 V		6	7		7		PO	γ	CD.
√2371.7 V	—	—			3		N ₂	Gaydon-Herman	L.
2371.1 V					10		NS	γ	CD.
*2370.2 V	5	10	10		10		NO	γ	DCD.
*2365.7 R		1	6		6		SiO		
*2364.5 R		4					SiO		
2364.5 R			8				BO	β	N.
*2363.5 R	3						C ₆ H ₆	Benzene	S.
2354.5 V	—	—			5		N ₂	Kaplan 2	c.
2352.5 R	—	—	—			6	CO ⁺	1st Negative	He.
2351.4 V	—	—	—		6		N ₂	4th Positive	F.
*2344.3 R		4	5		5		SiO		S.
*2342.4 R		4	1		1		SiO		
2342 M	10				10		Hg ₂		f.

TABLE OF PERSISTENT BAND HEADS

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .	System.	App.	Occ.
2340·3 M	10						CHOOH		
2333·8 R	9						As ₂		
2332·8 R					4		N ₂	Vegard-Kaplan	
2331·3 R			7				BO	β	N.
2330·4 R			6				BO	β	N.
2328·3 R	—	—			5		N ₂	Lyman	
*2326·6 R	—	—			3		NO	β	D.
2325 M	—	—			10		C ₂	Mulliken	hf.
2325·2 R	—	—	—			9	CO +	1st Negative	He.
2320·6 V		2	3		3		PO	γ	CD. S.
2319·7 R	10						As ₂		
*2317·7 V	0	—				3	NO	δ	DCD.
2317·3 V	8		10				AlF		
2317·2 V					10		NS	γ	CD.
2315·3 V	—	—			5		N ₂	Herman-Kaplan	
2313·7 V		3	4		4		PO	γ	CD.
2309·4 R	—	—			5		N ₂	Lyman	
2306·9 V			4		4		PO	γ	CD.
2306·0 R	10						As ₂		
2305·2 V					8		NS	γ	CD.
2301·7 V		3	4		4		PO	γ	CD.
2301·9 V					4		N ₂	Kaplan 1	c.
2299·6 R	—	—	—			10	CO +	1st Negative	He.
2298·9 R		2	6		6		SiO		S.
2295·9 V	—	—	—		4		CO	3A.	Fd.
2292·7 R	10						As ₂		
2290·5 R	—	—			5		N ₂	Lyman	
2288·9 V	9						SnCl		
2288·3 R	10						C ₂ H ₂		
2285·3 R	10						C ₂ H ₂		
2281·5 V	—	—			4		N ₂	Gaydon-Herman	L.
2284·9 M	10						CHOOH		c.
2279·6 R	10						As ₂		
2278·3 R	10		10				AlF		
2276·7 V			4				MgF		S.
2275·3 M	10						AlF		
2274·2 V	—	—			6		N ₂	5th Positive	c.
2271·7 R	—	—			5		N ₂	Lyman	
*2269·4 V	7	8	8		8		NO	γ	DCD.
2268·6 R	—	—	—			3	CO +	1st Negative	He.
2268·6 V	10						SnCl		
2266·7 R	9						As ₂		
2266·3 V	?						SnF		CD.
2264·8 R			6				BO	β	N ₂
2263·9 R	—	—				10	HgH ⁺		
2261·7 R					9		CO	4th Positive	
2260·8 V	—	—	—		2		N ₂	4th Positive	F.
2258·4 V					5		SiCl		D.
2257·7 R					1		CO	Cameron	F.
*2255·9 R		1	4		5		SiO		S.

THE IDENTIFICATION OF MOLECULAR SPECTRA

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .		System.	App.	Occ.
*2255-8 O				1			AlH			
2248-9 V	8						SnCl			
2246-9 R	9						AgI			
*2245-4 V	1	2	3		3		NO	γ	DCD.	
2244-9 R	8						Sb ₂			
2242-3 V	—	—			5		N ₂	Herman-Kaplan		
2239-3 R	8						AgI			
2239-2 R	2						CuH			
2238-3 R					9		CO	4th Positive		
2236-7 R	10						AgI			
*2236-3 R		1	2		2		SiO			
*2236-1 R					6		NO	β	D.	N.
2231-5 V					4		SiCl			
2229-2 R	9						AgI			
*2228-6 R				1			AlH			
*2226-8 V	0	—				4	NO	δ	DCD.	N. c.
2225-8 V					5		N ₂	Kaplan 1		c.
2222-8 R	10						Sb ₂			
*2222-4 V	0	1	3		3		NO	γ	DCD.	
2221-5 R					10		CO	4th Positive		
2221-0 R	9						TlF			
2217-5 V					?		O ₂	Hopfield		c. He.
*2215-4 R		0	2		2		SiO			
2214-5 R	—	—	—			5	CO +	1st Negative		He.
2209-4 R	8						Sb ₂			
2198-0 R	10						TlF			
2196-8 R					10		CO	4th Positive		
2189-8 R	—	—	—			10	CO +	1st Negative		He.
2188-2 R	9						C ₂ N ₂			
*2181-8 V	0		3		3		NO	ϵ	DCD.	
2173-0 R					9		CO	4th Positive		
2170-0 V					?		O ₂	Hopfield		c. He.
2165-1 V	—	—			5		N ₂	5th Positive		c.
2163-7 R	6						NH ₃		D.	
2157-1 V	?						SnF		CD.	
*2154-9 V	7	4	7		7		NO	γ	DCD.	
2153-6 V					4		N ₂	Kaplan 1		c.
2144-0 R					6		N ₂	Lyman		
*2142-8 R					3		NO	β	D.	N.
*2141-3 V	0	—				5	NO	δ	DCD.	N. c.
2137-8 R	—	—	—			6	CO +	1st Negative		He.
2125-9 R					9		N ₂	Lyman		
2123-9 R	6						NH ₃		D.	
2123-1 V					?		O ₂	Hopfield		c. He.
2113-1 R					9		CO	4th Positive		
2112-4 R	—	—	—			8	CO +	1st Negative		He.
2112-1 V	—	—			5		N ₂	5th Positive		c.
2112-1 V					?		N ₂	Kaplan 1		
2108-1 R	—	—			5		N ₂	Lyman		
*2103-6 R					2		NO	β	D.	N.

TABLE OF PERSISTENT BAND HEADS

	Ab.	F.	A(a).	A(r).	D ⁺ .	D ⁻ .		System.	App.	Occ.
*2099.8 V	0		3		3		NO	ε	DCD.	
2093.1 R	10						C ₂ N ₂			
2089.9 R					10		CO	4th Positive		
2084.1 R	7						NH ₃		D.	
*2078.2 V	0		3		3		NO	ε	DCD.	
2076.6 V					?		O ₂	Hopfield		c. He.
2074.4 R					10		ZnCl			hf.
2067.6 R					10		CO	4th Positive		
*2060.9 V	0	—				4	NO	δ	DCD.	N. c.
2059.6 R	6						CO	Cameron	F.	He. r.
2058.9 R	—	—				4	N ₂ ⁺			He.
*2052.8 V	7	0	4		4		NO	γ	DCD.	
2051.5 R	—	—				3	N ₂ ⁺			He.
2046.3 R	·				10		CO	4th Positive		
2045.7 R	9						NH ₃		D.	
2041.2 R					10		N ₂	Lyman		
2033.6 V	—	—			5		N ₂	5th Positive		c.
2030.8 V					?		O ₂	Hopfield		c. He.
2025.8 R					9		CO	4th Positive		
2023.5 R					7		N ₂	Lyman		
*2022.3 V	0		3		3		NO	ε	DCD.	
2010.9 R	10						NH ₃			
2007.0 R	10						C ₂ N ₂			
2006.0 R					4		N ₂	Lyman		

INDIVIDUAL BAND SYSTEMS

IN THIS SECTION detailed lists of bands are given for each system separately and are arranged in alphabetical order of the chemical symbols of the molecules concerned. The elements in the molecule are taken in the order which appears most frequently in the chemical literature, thus usually the more metallic element appears first as in CaCl, AgO, MgH, while OH is used in preference to HO, but HCl rather than ClH.

For each molecule a few general introductory remarks are made at the beginning if the spectrum is particularly important or complex, and then the various band systems are dealt with separately, the more important systems being given first. The treatment for the systems varies somewhat according to the particular case, but the spectrum is usually dealt with under some or all of the following headings:—

Occurrence. Mention is made of various sources from which the system has been obtained. This serves to give a general idea of the conditions which are most favourable to the production of the system, but does not of course imply that the bands cannot be obtained with some intensity in other sources. Arc sources usually refer to low voltage (100–200 v.) arcs running in air at atmospheric pressure. Where a band system is of very frequent occurrence as an impurity this is indicated.

Appearance. The direction in which the bands are shaded is recorded, *e.g.*, degraded to shorter wave-lengths, indicating that the bands have sharp heads on the red side and are shaded to the violet. A brief description of the system is given calling attention to any outstanding characteristics which help to identify it, *e.g.*, outstanding sequences, double-headed bands, line-like heads which might be mistaken for atomic lines.

Transition. The type of electronic transition is stated as this gives additional information as to the appearance of the system, especially when seen under high dispersion. Where the lower electronic level is known to be the normal or ground state this is also stated as such systems are likely to occur in absorption. A detailed account of the rotational structure and appearance of the various electronic transitions is beyond the scope of this work, but the following brief indications may be useful; the appearance depends greatly on the relative values of the molecular constants in the two electronic states and upon the dispersion with which the band is studied, and so certain bands may differ considerably from the following very brief generalisations:—

${}^1\Sigma \rightarrow {}^1\Sigma$. Single P and R branches. Single-headed.

${}^1\Sigma \rightarrow {}^1\Pi$, ${}^1\Pi \rightarrow {}^1\Sigma$. Single P, Q and R branches. Usually double-headed.

${}^2\Sigma \rightarrow {}^2\Sigma$. Double P and R branches, very weak satellite branches. Usually close double-headed.

${}^2\Pi \rightarrow {}^2\Pi$, ${}^2\Delta \rightarrow {}^2\Delta$. Two P and two R branches and short weak Q branches and satellite branches. Molecules with small spin (multiplet) splitting (Hund's case *b*) show double-headed bands; molecules with large spin splitting (Hund's case *a*) show two separate single-headed bands.

${}^2\Sigma \rightarrow {}^2\Pi$, ${}^2\Pi \rightarrow {}^2\Sigma$, ${}^2\Pi \rightarrow {}^2\Delta$, ${}^2\Delta \rightarrow {}^2\Pi$. Double P, Q and R branches and weak satellite branches. Often double double-headed. In Hund's case *b* the

doubling is small and the satellite branches are very weak. In Hund's case *a* the doubling is large so that the appearance is of two separate double-headed bands, and the satellite branches are stronger, forming definite heads in front of the main heads.

$^3\Sigma \rightarrow ^3\Sigma$. Triple P and R branches, weak Q and satellite branches. Close triple-headed.

References. References are given to those papers which are most useful for the purpose of identification. Those which contain useful photographs are indicated by a dagger following the date, *e.g.*, (1939)†. Often an early paper gives a far better general description of a system than later papers.

The following abbreviations are used :—

P.R. *Physical Review.*

P.R.S. *Proceedings of the Royal Society, Series A.*

Z.P. *Zeitschrift für Physik.*

In the lists of heads which follow, the wave-lengths are given to the nearest 0.1 Å., followed wherever possible by estimates of intensities and vibrational quantum numbers. In many cases the intensity estimates are made by the authors either from their own plates or from published photographs.

AgBr

Occurrence. In absorption and fluorescence.

Appearance. Single-headed bands degraded to the red.

Transition. Probably $^1\Sigma \rightarrow ^1\Sigma$ ground state.

References. J. Franck and H. Kuhn, *Z.P.*, **44**, 607. (1927).

B. A. Brice, *P.R.*, **38**, 658. (1931)†.

The bands observed in absorption by Brice are numerous and extend from 3500 Å. to 3165 Å. Those observed by Franck and Kuhn are in the region $\lambda\lambda 3393$ – 3182 . No intensities are given, but the following bands are probably among those most easily observed :—

λ	v', v''	λ	v', v''
3310.8	1, 5	3250.8	0, 2
3302.8	0, 4	3232.7	1, 2
3284.2	1, 4	3225.2	0, 1
3276.7	0, 3	3199.5	0, 0
3258.3	1, 3	3182.1	1, 0

R. F. Barrow and M. F. R. Mulcahy (*Nature*, Lond., **162**, 336 (1948)) have reported a system of bands, degraded to the red, $\lambda\lambda 2475$ – 2150 . They were obtained in absorption.

AgCl

STRONG SYSTEM, $\lambda\lambda 3379$ – 3114

Occurrence. In discharge tubes (including high-frequency discharge) containing silver chloride, in fluorescence and in absorption.

Appearance. Degraded to the red. Marked sequences.

Reference. B. A. Brice, *P.R.*, **35**, 960. (1930)†.

Strong bands as given by Brice :—

AgCl (contd.)

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3251.4	4	2, 4	3200.8	9	0, 1	3157.5	7	3, 2
3243.2	5	1, 3	3181.9	4	2, 2	3147.9	8	2, 1
3236.0	3	0, 2	3173.3	5	1, 1	3139.7	9	1, 0
3216.3	8	2, 3	3166.2	10	0, 0	3124.2	3	2, 1
3208.0	9	1, 2						

WEAKER SYSTEMS

Occurrence. In absorption.

Appearance. Degraded to red.

Reference. F. A. Jenkins and G. D. Rochester, *P.R.*, **52**, 1141. (1937).

$\lambda\lambda 2400-2200$. No intensities are given; the following may be the strong bands:—

λ	v', v''	λ	v', v''	λ	v', v''
2390.3	0, 5	2300.6	1, 1	2238.4	4, 0
2365.9	0, 4	2285.3	2, 1	2224.2	5, 0
2352.9	0, 3	2270.4	3, 1	2210.2	6, 0
2318.7	1, 2	2252.9	3, 0	2196.5	7, 0
2303.2	2, 2				

$\lambda\lambda 2200-2100$. No intensities given. The following may be the strong bands:—

λ	v', v''
2150.3	0, 8
2135.4	0, 7
2120.7	0, 6

OTHER BANDS

Reference. P. Mesnage, *C.R. Acad. Sci. Paris*, **200**, 2072. (1935).

Mesnage has observed the following bands, degraded to the red, in a high-frequency discharge through a heated quartz tube containing silver chloride; "the origin is not actually known." $\lambda\lambda 4608, 4560, 4509, 4427, 4390, 4199$; $\lambda\lambda 2822, 2806, 2802, 2791, 2778, 2775$ and 2764 .

AgH

References. E. Bengtsson and E. Olsson, *Z.P.*, **72**, 163. (1931).

E. Bengtsson, *Nova. Acta Reg. Soc. Sci. Uppsala (IV)*, **8**, No. 4. (1932).

3330 A. SYSTEM, $^1\Sigma \rightarrow ^1\Sigma$

Occurs in discharges where silver vapour is mixed with hydrogen. The bands given below were obtained by Bengtsson and Olsson in the spectrum of an arc in hydrogen between electrodes of silver aluminium alloy.

Bands with single R and P branches degraded to the red.

λ	v', v''	λ	v', v''	λ	v', v''
3179	1, 0	3583	2, 3	4108	4, 7
3220	2, 1	3637	3, 4	4190	5, 8
3275	3, 2	3710	4, 5	4273	6, 9
3330	0, 0	3740	1, 3	4328	4, 8
3357	1, 1	3781	2, 4	4397	5, 9
3396	2, 2	3833	3, 5	4472	6, 10
3451	3, 3	3905	4, 6	4536	7, 11
3516	0, 1	3990	5, 7	4669	6, 11
3546	1, 2	4039	3, 6		

Mention is made of other bands from 2700 A. to the further ultra-violet.

AgI

Occurrence. In emission from high-frequency discharges through the vapour. In absorption by the vapour at 700–900° C. Also observed in fluorescence by Franck and Kuhn.

NEAR ULTRA-VIOLET SYSTEM

References. J. Franck and H. Kuhn, *Z.P.*, **43**, 164. (1927).

B. A. Brice, *P.R.*, **38**, 658. (1931)†.

C. R. Sastry and K. R. Rao, *Ind. J. Phys.*, **19**, 136. (1945).

R. F. Barrow and M. F. R. Mulcahy, *Proc. Phys. Soc.*, **61**, 99. (1948).

Appearance. Bands degraded to the red $\lambda\lambda 3556$ – 3160 . Franck and Kuhn observed the shorter wave-length bands. Brice made measurements from 3295 Å. to longer wave-lengths. The intensities I_e are for emission in a high-frequency discharge and are due to Sastry and Rao. The intensities I_a are for absorption at about 900° C. and are due to Barrow and Mulcahy. Where the isotope separation is not resolved it may be assumed that settings on the low- λ side of the origin refer to ^{107}AgI heads and on the high- λ side to ^{109}AgI heads.

The following values taken from Brice are for ^{109}AgI .

λ	I_e	v', v''	λ	I_e	v', v''
3436.9	0	3, 12	3370.5		1, 8
3425.8	4	2, 11	3358.1		2, 8
3414.3	4	3, 11	3348.0		1, 7
3403.1	4	2, 10	3325.9	6	1, 6
3393.0	0	1, 9	3316.8	0	0, 5
3380.4		2, 9	3294.7	6	0, 4

Those below, from Barrow and Mulcahy, are for ^{107}AgI .

λ	I_a	I_e	v', v''	λ	I_a	I_e	v', v''
3273.4	8	6	0, 3	3208.9	5	8	0, 0
3270.5	2		2, 4	3206.6	3		2, 1
3251.7	10	8	0, 2	3196.8	6	2	1, 0
3249.1	2		2, 3	3185.4	7	4	2, 0
3239.4	3	2	1, 2	3175.5	3		3, 0
3238.6	1		3, 3	3166.8	2		4, 0
3230.3	9	8	0, 1	3160.3	1		5, 0
3217.9	7	2	1, 1	3157.9	0		6, 0

FAR ULTRA-VIOLET SYSTEM

References. N. Metropolis, *P.R.*, **55**, 636. (1939).

R. F. Barrow and M. F. R. Mulcahy, *Nature, Lond.*, **162**, 336. (1948).

Occurrence. In absorption 700–900° C. At higher temperatures the system is overlapped by continuum spreading from shorter wave-lengths.

Appearance. About thirty-nine sharp band heads in the region $\lambda\lambda 2175$ – 2350 .

Bands degrade to the red and form sequences. Most intense bands near $\lambda 2230$.

Transition. To ground state.

AgI (*contd.*)

λ	v', v''	λ	v', v''	λ	v', v''
2330.8	0, 9	2259.9	1, 3	2236.7	0, 0
2320.1	0, 8	2257.2	0, 2	2234.7	3, 2
2309.6	0, 7	2252.3	2, 3	2231.9	2, 1
2298.9	0, 6	2249.6	1, 2	2229.2	1, 0
2288.4	0, 5	2246.9	0, 1	2224.7	3, 1
2277.9	0, 4	2242.0	2, 2	2221.9	2, 0
2267.5	0, 3	2239.3	1, 1	2214.7	3, 0

Metropolis also records a set of bands farther to the ultra-violet which may form part of another system, $\lambda\lambda 2211.2, 2209.8, 2208.3, 2203.7, 2201.9, 2200.1, 2194.2, 2192.4, 2190.3$.

AgO

Occurrence. Arc between silver poles in an atmosphere of oxygen.

Reference. F. W. Loomis and T. F. Watson, *P.R.*, **48**, 280. (1935).

There are two strong band systems attributed to AgO, in the blue and ultra-violet, and some faint bands have been observed (but not measured) in the red.

BLUE SYSTEM

Appearance. Degraded to red.

Transition. ${}^2\Pi \rightarrow {}^2\Sigma$, ground state.

The following are presumably the R_1 and R_2 heads. A few weak bands are omitted. Intensities on a scale of 5.

λ	I	v', v''	λ	I	v', v''
4614.6	1	0, 5	4337.4	2	0, 2
4577.9	1		4304.7	2	
4519.7	2	0, 4	4294.0	3	1, 2
4484.6	2		4262.8	3	
4427.4	1	0, 3	4207.6	4	1, 1
4393.8	3		4177.5	4	
4382.4	2	1, 3	4123.6	5	1, 0
4349.8	0		4094.5	5	

ULTRA-VIOLET SYSTEM

Appearance. Degraded to shorter wave-lengths. Marked sequences.

Transition. ${}^2\Sigma \rightarrow {}^2\Sigma$, ground state.

P heads of strong bands. Intensities on a scale of 5.

λ	I	v', v''	λ	I	v', v''
3620.7	2	0, 1	3493.5	2	1, 0
3614.9	2	1, 2	3490.2	3	2, 1
3609.3	2	2, 3	3487.8	3	3, 2
3558.4	4	0, 0	3484.2	1	5, 4
3553.5	5	1, 1	3481.4	1	—

AlBr

Occurrence. High-frequency discharge through aluminium tribromide vapour.

Appearance. Degraded to the red. Close double-headed bands, separation between the R and Q heads being about 0.2 Å.

Transition. ${}^1\Pi \rightarrow {}^1\Sigma$, ground state.

References. H. G. Howell, *P.R.S.*, **148**, 696. (1935)†.

C. G. Jennergren, *Nature*, Lond., **161**, 315. (1948).

The following are the R heads of the strong bands :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
2855.3	7	1, 3	2804.9	8	2, 2
2848.0	6	0, 2	2796.3	9	1, 1
2834.1	8	2, 3	2788.8	10	0, 0
2825.6	8	1, 2	2775.8	8	2, 1
2818.3	9	0, 1	2767.2	9	1, 0

AlCl

Occurrence. Uncondensed discharge through AlCl₃ vapour. This system is frequently observed as an impurity in discharge tubes with aluminium electrodes.

Appearance. As may be seen from Plate 1, this system is of rather complex structure. The (2, 0), (1, 0) and (0, 0) sequences are degraded to the red, and the bands are close double-headed, with additional weak heads due to the less abundant isotope of chlorine. Some of the bands of the (0, 2) and (0, 1) sequences are degraded to shorter wave-lengths. The heads of the (0, 0) band at 2610 and 2614 Å. are usually outstanding if the system is only weakly present, *e.g.*, as an impurity.

Transition. ${}^1\Pi \rightarrow {}^1\Sigma$, probably ground state.

References. B. N. Bhaduri and A. Fowler, *P.R.S.*, **145**, 321. (1934)†.

W. Holst, *Z.P.*, **93**, 55. (1934-35).

The following measurements of the outstanding heads are from Bhaduri and Fowler. Intensities are on a scale of 8. Weaker isotope heads are omitted, and for the close double-headed bands degraded to the red, only the R heads are given, the Q heads being usually less than 1 Å. to the red. The letters R or V after the wave-length indicate the direction of degradation of the band, while the nature of the head (R or Q) is indicated before the vibrational quantum numbers.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
2708.9 R	2	R 7, 9	2623.5 R	5	Q 3, 3
2702.3 R	3	R 6, 8	2622.4 R	4	R 3, 3
2696.4 R	3	R 5, 7	2620.0 R	4	Q 2, 2
2692.8 R	5	Q 4, 6	2618.2 R	3	R 2, 2
2685.7 V	6	Q 2, 4	2617.0 R	4	Q 1, 1
2683.1 V	6	Q 1, 3	2614.4 R	8	Q 0, 0
2681.1 V	4	Q 0, 2	2610.2 R	6	R 0, 0
2649.7 V	4	Q 1, 2	2606.7 R	2	R 6, 5
2647.5 V	6	Q 0, 1	2600.7 R	3	R 5, 4
2644.9 R	2	R 7, 7	2595.4 R	2	R 4, 3
2638.1 R	3	R 6, 6	2590.8 R	2	R 3, 2
2632.8 R	3	Q 5, 5	2586.7 R	2	R 2, 1
2632.2 R	3	R 5, 5	2564.3 R	1	R 4, 2
2627.8 R	4	Q 4, 4	2559.6 R	1	R 3, 1
2627.0 R	3	R 4, 4	2555.5 R	1	R 2, 0

R 1, 1

AIF

NEAR ULTRA-VIOLET SYSTEM

Occurrence. Discharge through heated tube containing AlF_3 .

Appearance. Degraded to the red ; marked sequences.

Reference. T. Yuasa, *Sci. Rep. Tokyo Bunrika Daigaku*, 3A, 239. (1938)†.

Heads of strongest sequences.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
4039.8	3	0, 7	3732.5	3	0, 4	3465.4	2	0, 1
3931.7	4	0, 6	3640.4	3	0, 3	3383.9	2	0, 0
3830.2	4	0, 5	3550.7	2	0, 2	3309.2	2	1, 0
						3244.2	2	2, 0

The published analysis, as reproduced above, appears far from convincing, as the strongest bands fall on a very open Franck-Condon parabola which would not be expected from an analysis using nearly equal values of ω' and ω'' . As far as can be seen from the published photographs, many of the strongest heads are unassigned.

FAR ULTRA-VIOLET SYSTEM

Occurrence. In absorption.

Reference. G. D. Rochester, *P.R.*, 56, 305. (1939)†.

The system is very symmetrical, being hardly degraded in either direction. The (0, 0) band shows a line-like Q branch at 2278.3 Å. and headless P and R branches on each side. The (1, 0) sequence shows a head at 2234.4 Å. degraded to the red. The (0, 1) sequence shows a head at 2317.3 Å. degraded to shorter wave-lengths.

AlH

Some eight band systems are attributed to AlH. Under conditions of mild excitation the $\lambda 4241$ system is the strongest. The prominent heads at 4241 Å and 4259 Å are frequently observed in discharge tubes with aluminium electrodes.

References. E. Bengtsson and R. Rydberg, *Z.P.*, 59, 540. (1930).

J. W. I. Holst, *Dissertation, Stockholm*. (1935).

W. Holst and E. Hulthén, *Z.P.*, 90, 712. (1934)†.

E. Olsson, *Z.P.*, 104, 402. (1936).

E. Bengtsson, *Z.P.*, 51, 889. (1928).

B. E. Nilsson, *Ark. Mat. Astr. Fys.*, 35 A, (Paper 19) 10 (1948).

4241 Å. SYSTEM, $B^1\Pi \rightarrow A^1\Sigma$, GROUND STATE

Double-headed bands of open structure degraded to the red. Occurs readily in emission in discharges where aluminium vapour and hydrogen are present together. May also be obtained in absorption.

v', v''	Origins	R.	Heads	Q.
1, 2	4680.5	4670.9		4680.7
0, 1	4576.3	4546.5		4576.4
1, 1	4360.1	4353.1		4360.5
0, 0	4259.3	4241.0		4259.5
1, 0	4071.6	4066.3		4072.6

AIH (*contd.*)2229 A. SYSTEM, C $^1\Sigma \rightarrow$ A $^1\Sigma$, GROUND STATE

Weak bands with P and R branches slightly degraded towards the red.

v', v''	Origins	Head R.
0, 0	2241.6	2228.6
1, 1	2255.8	
1, 2	2326.3	

2033 A. SYSTEM, D $^1\Sigma \rightarrow$ A $^1\Sigma$, GROUND STATE

Weak band with P and R branches, neither forming definite head. The P branch stretches to about 2033 A.

v', v''	Origin
0, 0	2028.2

4752 A. SYSTEM, C $^1\Sigma \rightarrow$ B $^1\Pi$

Bands show P, Q and R branches degraded to the violet.

Head Q
4731.8

4980 A. SYSTEM, E $^1\Sigma \rightarrow$ B $^1\Pi$

Obtained in an arc between aluminium and carbon electrodes in hydrogen. Band shows P, Q and R branches degraded to the red.

v', v''	Origin	R.	Heads Q.
0, 0	4988	4886	4929

3380 A. SYSTEM, F $^1\Pi \rightarrow$ B $^1\Pi$

Bands degraded to the red, each with two P and two R branches.

v', v''	Origin	Heads
0, 0	3390	3379.4 3384.8

3800 A. SYSTEM, b $^3\Sigma \rightarrow$ a $^3\Pi$ *Reference.* W. Holst, *Z.P.*, **86**, 338. (1933).

Triplet bands with three P and three R branches symmetrically arranged about piled up Q branches; similar to the 3360 A. band of NH. The (1, 1) band shows a weaker Q maximum on the long wave side of the (0, 0).

v', v''	Origin
0, 0	3812.6

2700 A. SYSTEM. Brief mention of a band about 2700 A.

Reference. W. Holst, *Z.P.*, **89**, 47. (1934).AIH⁺*References.* W. Holst, *Z.P.*, **89**, 40. (1934)†.G. M. Almy and M. C. Watson, *P.R.*, **45**, 871. (1934)†.

AlH⁺ (*contd.*)**3602 A. SYSTEM, ${}^2\Pi \rightarrow {}^2\Sigma$**

Bands degraded to the violet. Observed in arc between Al electrodes in hydrogen at reduced pressures, in discharge through a mixture of AlCl₃ vapour and hydrogen, and in hollow aluminium cathode containing hydrogen and helium.

(0, 0) Band	(1, 1) Band
3632.3 P ₁	3600.5 P ₂
3630.2 P ₂	3593.0 Q ₁
3611.9 Q ₁	3583.0 Q ₂
3602.4 Q ₂	

AlI

Occurrence. In discharge tubes of various types containing aluminium iodide, and in absorption.

Appearance. Two systems in the blue, degraded to the violet, and a single progression of diffuse bands in the ultra-violet.

References. E. Miescher, *Helv. Phys. Acta.*, **8**, 279. (1935)†.
E. Miescher, *Helv. Phys. Acta.*, **9**, 693. (1936)†.

SYSTEM A, A ${}^3\Pi \rightarrow {}^1\Sigma$, GROUND STATE

Strongest bands :

λ	<i>I</i>	v', v''
4631.4	7	0, 1
4565.0	10	0, 0
4561.1	8	1, 1
4496.6	8	1, 0
4431.0	3	2, 0

SYSTEM B, B ${}^3\Pi \rightarrow {}^1\Sigma$, GROUND STATE

Strongest bands :

λ	<i>I</i>	v', v''
4589.2	2	0, 1
4524.0	7	0, 0
4520.9	4	1, 1

ULTRA-VIOLET SYSTEM, ${}^1\Pi \rightarrow {}^1\Sigma$, GROUND STATE

λ	v', v''	λ	v', v''
3426	0, 5	3295	0, 2
3382	0, 4	3244	0, 1
3339	0, 3	3175	0, 0

OTHER BANDS

Miescher also records numerous bands, degraded to the red, in the blue and violet.

A10

Occurrence. Aluminium arc in air and Al salts in carbon arc.

Appearance. Degraded to red. Marked sequences of single-headed bands. See Plate I.

Transition. B ${}^2\Sigma \rightarrow {}^2\Sigma$, ground state.

References. W. C. Pomeroy, *P.R.*, **29**, 59. (1927)†.

G. Eriksson and E. Hulthén, *Z.P.*, **34**, 775. (1929).

The following heads are taken from unpublished spectrograms by W. Jevons. Weak bands are omitted.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
5424.3	2	5, 7	5102.1	5	1, 2	4648.2	8	1, 0
5410.5	3	4, 6	5079.3	4	0, 1	4557.5	3	6, 4
5394.8	3	3, 5	4888.4	6	2, 2	4537.6	4	5, 3
5377.4	2	2, 4	4866.1	9	1, 1	4516.3	4	4, 2
5358.1	2	1, 3	4842.1	10	0, 0	4494.0	3	3, 1
5336.9	1	0, 2	4735.5	6	5, 4	4470.5	2	2, 0
5160.8	3	4, 5	4715.5	6	4, 3	4393.8	1	7, 4
5142.9	4	3, 4	4694.6	7	3, 2	4373.7	1	6, 3
5123.3	5	2, 3	4672.0	8	2, 1			

F. P. Coheur and B. Rosen (*Mem. Soc. roy. Sci. Liège*, 405 (1941)) have reported two new systems in spectrum of exploding wires. Both systems degraded red. Strongest heads,

$\lambda\lambda 3112.6$ (0,1), 3021.6 (0,0), 2946.6 (1,0)

$\lambda\lambda 2592.9$ (0,0), 2561.0 (2,1), 2545.8 (1,0), 2500.1 (2,0)

As₂

Occurrence. In discharge tube (with hydrogen as a carrier of the discharge) containing arsenic vapour, in absorption and in fluorescence.

Appearance. A very extensive system of bands degraded to the red.

Transition. The bands have been analysed by Almy and Kinzer into two strong and two weak systems, all having the same final level which is probably ${}^1\Sigma$. The intensity distribution of all these systems is far from smooth.

References. G. E. Gibson and A. MacFarlane, *P.R.*, **46**, 1059. (1934)†.

G. M. Almy and G. D. Kinzer, *P.R.*, **47**, 721. (1935).

G. D. Kinzer and G. M. Almy, *P.R.*, **52**, 814. (1937)†.

The strongest bands as listed by Almy and Kinzer are given below. The letter A in the intensity column indicates that the band is observed strongly in absorption.

SYSTEM A, $\lambda\lambda 5555-2240$

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3715.3	4	14, 45	3140.5	4	6, 25 9, 27	2956.0	4	2, 17
3543.0	4	14, 41	3104.5	5	6, 24 9, 26	2931.5	4	6, 19
3501.6	4	14, 40	3093.5	5	5, 23	2922.9	5	8, 20
3368.7	4	9, 33	3069.0	5	9, 25	2922.3	5	5, 16
3329.0	4	9, 32	3058.0	4	8, 24	2889.1	5	2, 15
3318.0	5	8, 31	3011.0	4	7, 22	2856.4	5	2, 14
3240.5	4	8, 29	2965.0	4	6, 20	2846.4	4	4, 15

As₂ (*contd.*)

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
2803.3	4	6, 15	2570.4	5	6, 7	2424.9	5	7, 2
2753.7	4	7, 14	2551.6	5	4, 5	2410.6	4	8, 2
2712.3	4	6, 12	2533.4	4	5, 5	2357.1	A	10, 1
2683.1	4	6, 11	2506.9	6	5, 4	2333.8	A	10, 0
2658.9	4	9, 12	2490.6	4	6, 4	2319.7	A	11, 0
2644.0	4	5, 9	2480.7	5	5, 3	2306.0	A	12, 0
2637.0	4	7, 10	2464.7	5	6, 3	2292.7	A	13, 0
2592.7	4	8, 9	2455.0	4	5, 2	2279.6	A	14, 0
2587.9	4	5, 7	2449.9	6	7, 3	2266.7	A	15, 0
2578.9	4	4, 6	2439.4	5	6, 2	2254.0	A	16, 0

SYSTEM B, $\lambda\lambda 5530-2350$								
λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
4376.0	4	2, 50	3141.8	5	1, 23	2659.8	4	5, 11
4312.0	4	7, 53	3113.8	5	2, 23	2638.6	5	0, 7
4129.5	4	0, 44	3105.1	5	1, 22	2615.6	4	6, 10
4074.8	4	0, 43	3077.6	4	2, 22	2588.0	4	6, 9
3188.4	4	2, 25	3033.2	4	1, 20	2554.4	5	0, 4
3159.3	4	3, 25	2998.3	5	1, 19	2420.1	4	5, 2
3150.6	5	2, 24	2963.9	4	1, 18			

SYSTEM C, $\lambda\lambda 3390-2980$

λ	<i>I</i>	v', v''
3235.9	3	0, 28
3198.2	3	0, 27

SYSTEM D, $\lambda\lambda 5580-3760$

λ	<i>I</i>	v', v''
4317.9	3	2, 5
3870.5	3	5, 1

Bands observed by Winand (*Bull. de la classe des sciences, Acad. Roy. de Belgique* (5), 18, 422 (1932)) in a high-frequency discharge have been identified with CO by Almy and Kinzer.

As₂⁺

Occurrence. In discharge tube containing arsenic vapour, with hydrogen to carry the discharge.

Appearance. Degraded to the violet.

Reference. G. D. Kinzer and G. M. Almy, *P.R.*, 52, 814. (1937)†.

The following are the strong bands as listed by Kinzer and Almy. The bands are attributed to the ionised molecule because of their doublet character. Intensities on a scale of 3.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
6550.5	2	0, 3 i	6115.2	2	0, 0 ii
6482.3	2	0, 3 ii	6051.3	3	1, 0 i
6422.0	2	0, 2 i	5992.6	3	1, 0 ii
6356.0	2	0, 2 ii	5932.7	2	2, 0 i
6297.3	2	0, 1 i	5926.2	2	3, 1 i
6234.4	2	0, 1 ii	5875.9	3	2, 0 ii
6176.8	2	0, 0 i	5869.4	2	3, 1 ii

AsH

Reference. G. E. Kimball and J. R. Bates, *Nature*, **128**, 969. (1931).

Using a carbon arc, with the negative electrode drilled and filled with arsenic, run in an atmosphere of hydrogen, Kimball and Bates observed three bands. Two of these with origins at 3160.0 Å. and 3087.4 Å. showed only P and R branches with wide-spaced lines degraded to the red and appeared to be due to a ${}^1\Sigma' \rightarrow {}^1\Sigma'$ transition. These were attributed to AsH. The third band at 3143.5 was unresolved and considered to have another origin, possibly As₂. It is to be noted that there is a CH band with Q head at 3143.4.

AsN

Occurrence. In heavy-current discharge tubes containing arsenic and nitrogen.

Appearance. Degraded to the red. The bands presumably have close double heads.

Transition. Probably ${}^1\Pi \rightarrow {}^1\Sigma$.

Reference. J. W. T. Spinks, *Z.P.*, **88**, 511. (1934)†.

The following are the bands as listed by Spinks :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3051.0	2	0, 3	2784.2	10	0, 0
3007.8	1	3, 5	2719.5	7	1, 0
2884.7	3	1, 2	2675.6	4	3, 1
2868.7	6	0, 1	2656.5	5	2, 0
2833.5	1	3, 3	2602.0	2	3, 0

AsO

Occurrence. Carbon arc in air with arsenic salts on poles, high-tension arc between metallic arsenic electrodes, and in discharge tube containing As₂O₃.

References. F. C. Connelly, *Proc. Phys. Soc.*, **46**, 790. (1934)†.

F. A. Jenkins and L. A. Strait, *P.R.*, **47**, 136. (1935)†.

SYSTEM A, $\lambda\lambda 3450-2950$

Appearance. Degraded to red. Evenly spaced bands with close double heads.

Transition. $A^2\Sigma' \rightarrow {}^2\Pi$, ground state.

Strong heads only, as measured by Connelly. Intensities on scale of 9.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3310.7	4	1, 1 ii Q	3172.4	8	0, 0 i Q
3279.1	9	0, 0 ii Q	3170.6	5	0, 0 i R
3277.2	8	0, 0 ii R	3144.1	4	2, 0 ii Q
3241.4	4	2, 1 ii Q	3137.2	4	2, 1 i Q
3209.1	6	1, 0 ii Q	3135.6	4	2, 1 i R
3207.8	4	1, 0 ii R	3106.8	6	1, 0 i Q
3202.0	4	1, 1 i Q	3105.6	4	1, 0 i R

SYSTEM B, $\lambda\lambda 2800-2350$

Appearance. Degraded to shorter wave-lengths. Marked sequences of close double-headed bands.

Transition. $B^2\Sigma \rightarrow {}^2\Pi$, ground state.

THE IDENTIFICATION OF MOLECULAR SPECTRA

AsO (contd.)

Strong bands only, by Connolly. Intensities on scale of 9 for (0, 0) band of system A.

λ	I	v', v''	λ	I	v', v''
2635.5	4	0, 1 ii P	2504.7	6	0, 0 i P
2634.4	5	0, 1 ii Q	2503.6	7	0, 0 i Q
2624.7	4	1, 2 ii Q	2438.5	3	1, 0 i P
2570.9	6	0, 0 ii P	2437.3	4	1, 0 i Q
2569.7	8	0, 0 ii Q			
2565.2	4	0, 1 i Q			

AuCl

Occurrence. Gold chloride in active nitrogen.

Appearance. Two overlapping systems in the green, both degraded to the red.

Transition. Both systems have common final level, probably the ground state.

Reference. W. F. C. Ferguson, *P.R.*, 31, 969. (1928)†.

Strong bands only. Intensities on a scale of 5.

SYSTEM A

λ	I	v', v''	λ	I	v', v''
5590.2	2	1, 4	5346.6	5	0, 1
5570.4	2	0, 3	5240.0	5	0, 0
5476.0	2	1, 3	5155.9	4	1, 0
5456.8	4	0, 2	5075.0	1	2, 0

SYSTEM B

λ	I	v', v''	λ	I	v', v''
5531.7	1	0, 3	5205.5	5	0, 0
5437.6	2	1, 3	5121.9	4	1, 0
5419.4	3	0, 2	5041.7	1	2, 0
5310.6	5	0, 1			

AuH

References. E. Bengtsson, *Ark. Mat. Astr. Fys.* 18, 27. (1925).

T. Heimer, *Z.P.*, 104, 303. (1937).

3656 A. SYSTEM, $^1\Sigma \rightarrow ^1\Sigma$

Bands with single R and P branches degraded to the red. Occurs in gold arc in hydrogen.

Origins		Heads
v', v''	λ	R. (I.)
0, 3	4772.2	
1, 3	4444.1	4436.6 2
0, 2	4347.8	4339.4 3
1, 2	4073.7	4068.2 3
0, 1	3978.9	3972.8 10
1, 1	3748.1	
0, 0	3656.0	3651.5 9
1, 0	3460.2	3457.4 2
2, 0	3300.3	
3, 0	3171.4	

AuH (contd.)2615 A. SYSTEM, $^1\Sigma \rightarrow ^1\Sigma$

Bands degraded to the red with single P and R branches.

v', v''	Origins λ
0, 2	2950.0
0, 1	2776.0
0, 0	2614.8

B₂

Occurrence. Boron trichloride in active nitrogen. Discharges in helium with a trace of boron trichloride.

Appearance. Bands with single P and R branches degraded to the red.

Transition. $^3\Sigma_u \rightarrow ^3\Sigma_g^-$, ground state.

References. A. E. Douglas and G. Herzberg, *P.R.*, **57**, 752. (1940).

A. E. Douglas and G. Herzberg, *Can. J. Res.*, **A18**, 165. (1940)†.

Bands were observed for the molecules $B^{11}B^{11}$ and $B^{10}B^{11}$. The heads for the more abundant molecule $B^{11}B^{11}$ are given below.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3300.4	1	3, 3	3204.2	0	4, 3
3292.7	5	2, 2	3196.4	2	3, 2
3283.4	8	1, 1	3187.0	2	2, 1
3272.8	10	0, 0	3176.5	3	1, 0

BBr

Occurrence. In electrodeless high-frequency discharge through BBr_3 and in absorption.

Appearance. Bands degraded in each direction.

Transition. $^1\Pi \rightarrow ^1\Sigma$, ground state.

Reference. E. Miescher, *Helv. Phys. Acta*, **8**, 279. (1935)†.

E. Miescher and E. Rosenthaler, *Nature*, Lond., **145**, 624. (1940).

Prominent heads as listed by Miescher. The letters R or V following the wave-length indicate that the head is degraded to longer or shorter wave-lengths respectively.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3094.5 R	5	3, 5 Q	2954.4 V	10	1, 1 Q
3082.7 R	5	2, 4 Q'	2954.0 R	10	1, 1 Q'
3010.3 V	5	0. 1 P	2951 —	8	0, 0 P
2973.0 R	7	3, 3 R	2948.1 V	10	0, 0 Q
2963.1 R	8	2, 2 Q	2944.2 R	9	0, 0 Q'
2959.9 R	7	2, 2 R	2935.7 R	7	0, 0 R

BCl

Occurrence. In high-frequency electrodeless discharge through BCl_3 . Also in uncondensed discharge through helium with small amount of BCl_3 present.

Appearance. Well-developed sequences degraded to the violet with some bands degraded to the red.

Transition. $^1\Pi \rightarrow ^1\Sigma$, ground state.

BCl (*contd.*)

References. E. Miescher, *Helv. Phys. Acta.*, **8**, 279. (1935)†.

G. Herzberg and W. Hushley, *Can. J. Res.*, **A19**, 127. (1941)†.

Prominent heads as listed by Miescher. The letters R and V following the wave-length indicate that the head is degraded to longer or shorter wave-lengths respectively.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
2880.6 R	6	7, 9 Q	2786.7 V	8		2723.6 R	8	2, 2 ?
2867.1 R	7	5, 7 R	2786.4 R	8		2722.2 V	10	0, 0 P
2860.4 R	10	5, 7 Q	2784.4 V	8		2721.7 V	10	1, 1 Q
2859.2 R	8	5, 7 Q*	2784.1 V	8		2720.0 V	10	0, 0 Q
2857.3 R	7		2783.7 V	9		2714.2 R	8	
2847.5 V	7		2733.3 R	9	4, 4 Q	2669.7 R	8	3, 2 Q
2847.3 V	7		2727.8 V	9	3, 3 Q	2665.3 V	9	2, 1 Q
2796.1 R	8	4, 5 Q**	2727.4 R	10	3, 3 Q'	2664.9 R	9	2, 1 Q'
2792.7 R	8	4, 5 Q	2727.2 R	8	3, 3 Q'*	2660.2 V	8	1, 0 Q**
2792.4 R	9	4, 5 Q'	2724.0 V	10	2, 2 Q	2659.8 R	8	1, 0 Q'***

* Head due to isotope B¹¹Cl³⁵.

** Head due to isotope B¹⁰Cl³⁷.

Other bands due to B¹¹Cl³⁷.

Bands whose analysis is not given are due to the piled up (0, 2), (0, 1) or (0, 0) sequences, the bands of which are very close at the head of the sequence.

Q heads of B¹¹Cl³⁵ and B¹⁰Cl³⁵(‡) as given by Herzberg and Hushley.

λ	v', v''	λ	v', v''	λ	v', v''
2790.7	4, 5‡	2728.6	4, 4‡	2675.1	5, 4‡
2787.8	4, 5	2727.8	4, 4	2669.7	4, 3
2787.0	3, 4‡	2724.4	3, 3‡	2668.5	4, 3‡
2785.0	0, 1‡	2724.0	3, 3	2665.3	3, 2
2784.4	3, 4	2721.5	2, 2	2663.7	3, 2‡
2782.7	0, 1; 2, 3	2720.3	1, 1‡	2662.1	2, 1
2782.2	1, 2	2720.2	1, 1	2660.2	1, 0; 2, 1‡
2734.7	5, 5‡	2720.0	0, 0; 0, 0‡	2658.1	1, 0‡
2733.4	5, 5	2675.7	5, 4	2604.7	2, 0
				2600.7	2, 0‡

BF

There are two systems of bands in the visible which have not been analysed and two systems in the ultra-violet.

Occurrence. In discharge tubes containing BF₃, and especially in a high-frequency electrodeless discharge for the ultra-violet systems.

References. R. B. Dull, *P.R.*, **47**, 458. (1935)†.

H. M. Strong and H. P. Knauss, *P.R.*, **49**, 740. (1936)†.

YELLOW SYSTEM, $\lambda\lambda$ 6400–5646

Appearance. Diffuse bands degraded to the violet.

Strong heads as listed by Dull :—

λ	<i>I</i>	λ	<i>I</i>
5993.8	8	5815.1	8
5984.4	6	5807.3	6
5825.7	7	5803.8	6
5822.1	10	5664.0	6

BF (contd.)**BLUE-GREEN SYSTEM, $\lambda\lambda 5476-4439$**

Appearance. Diffuse bands degraded to the red.

Strong bands as listed by Dull :—

λ	<i>I</i>	λ	<i>I</i>
5470.8	6	4464.9	8
5460.1	4*	4461.4	6
5456.8	8	4443.5	6

* Intensity given as 10 by Johnson and Tawde.

ULTRA-VIOLET SYSTEMS

Appearance. Degraded to shorter wave-lengths. Bands with five heads, similar in appearance to the CO third positive bands.

Transition. Two systems with a common lower level, probably either ${}^3\Pi \rightarrow {}^3\Sigma$ or ${}^3\Sigma \rightarrow {}^3\Pi$.

System A. All five heads of the (0, 0) band and the P_3 heads of the other strong bands as listed by Strong and Knauss.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3549.8	4	0, 3	3124.1	2	0, 0 O
3396.9	3	0, 2	3122.1	7	P_3
3359.7	2	1, 3	3121.2	9	P_2
3254.8	5	0, 1	3120.3	9	P_1
3222.9	1	1, 2	3118.4	9	Q_1
			2974.8	4	1, 0
			2844.5	2	2, 0

System B. Similar to above. P_3 heads of the three bands given by Strong and Knauss.

λ	<i>I</i>	v', v''
2824.0	3	0, 2
2724.9	4	0, 1
2631.4	7	0, 0

BH

References. S. F. Thunberg, *Z.P.*, **100**, 471. (1936).

G. M. Almy and R. B. Horsfall, *P.R.*, **51**, 491. (1937).

4332 A. SYSTEM, ${}^1\Pi \rightarrow {}^1\Sigma$

Bands degraded to the red consisting of single P, Q and R branches. The Q head is very intense through superposition of several lines.

Observed in hollow cathode containing boron and hydrogen and from a discharge through a mixture of hydrogen and BCl_3 .

v', v''	Q Heads	R Heads
0, 0	4331.6	4245.9
1, 1	4367.3	4319.2
2, 2	4433.7	

BH (*contd.*)**3662 A. SYSTEM, ${}^3\Sigma \rightarrow {}^3\Pi$**

Bands obtained under similar conditions to those described above. Degraded to the red.

v', v''	Q Head	R Head
0, 0	3693.8	3662.4

3415 A. SYSTEM, ${}^1\Sigma^+ \rightarrow {}^1\Pi$

References. A. E. Douglas and G. Herzberg, *P.R.*, **57**, 752. (1940).

A. E. Douglas, *Canad. J. Res.*, **A19**, 27. (1941).

Occurrence. In uncondensed discharge through helium containing a small amount of hydrogen and BCl_3 .

Appearance. Single P, Q and R branches degraded to shorter wave-lengths. The structure is very open, so for the Q heads the wave-lengths of the first lines of the Q branch may be given. $\lambda\text{Q}(1)$: 3415.1 (0, 0), 3396.4 (1, 1).

3099 A. SYSTEM, ${}^1\Sigma^+ \rightarrow {}^1\Pi$

Reference. A. E. Douglas, *Canad. J. Res.*, **A19**, 27. (1941).

Douglas reports a single band very similar in structure to the two bands of the 3415 A. system, but apparently belonging to another system. $\lambda\text{Q}(1)$: 3098.9. If this is the only band of the system it is presumably the (0, 0) band.

BH⁺

References. G. M. Almy and R. B. Horsfall, *P.R.*, **51**, 491. (1937).

3768 A. SYSTEM, ${}^2\Pi \rightarrow {}^2\Sigma$

Bands showing P, Q and R branches degraded to the red, each consisting of narrow doublets. Obtained with a hollow cathode of the Schüller type containing boron, hydrogen and helium.

v', v''	R Heads	Q Head
0, 0	3768.1	3792
1, 1	3803	

BN

Occurrence. In a discharge through helium containing traces of BCl_3 and nitrogen.

Reference. A. E. Douglas and G. Herzberg, *Canad. J. Res.*, **A18**, 179. (1940)†.

TRIPLET SYSTEM, 3400–4000 Å.

Appearance. Bands with R heads degraded to longer wave-lengths.

Transition. ${}^3\Pi \rightarrow {}^3\Pi$, probably ground state.

R heads B^{11}N and B^{10}N (*)

λ	v', v''	λ	v', v''	λ	v', v''
3496.3	3, 2	3681.8	3, 3	3856.1	2, 3
3494.1	3, 2*	3653.2	2, 2	3836.2	1, 2*
3467.4	2, 1	3625.6	1, 1	3829.3	1, 2
3464.4	2, 1*	3599.2	0, 0	3809.3	0, 1*
3439.7	1, 0			3803.2	0, 1
3435.8	1, 0*				

BN (contd.)

SINGLET SYSTEM, 2900–3250 Å.

Under the same conditions as for the triplet system three further bands were observed with their main heads at 3228.7, 3046.3 and 2897.8 and weaker heads at 3226.4, 3044.3 and 2895.9 Å. Possibly the (0, 1), (0, 0) and (1, 0) bands of the same system, but the first is degraded violet, the others degraded red.

Transition. Possibly ${}^1\Pi \rightarrow {}^1\Sigma$.

BO

There are two strong band systems attributed to boron monoxide, usually known as the α and β systems, and a third weak intercombination system.

 α SYSTEM, $\lambda\lambda 8519$ – 3136

Occurrence. In arcs containing B_2O_3 and in boron arc in air. The bands are also very well developed when a volatile boron compound such as BCl_3 is introduced into active nitrogen containing a trace of oxygen.

Appearance. Degraded to the red. Double double-headed bands (see Plate 10).

Transition. A ${}^2\Pi \rightarrow {}^2\Sigma$, ground state.

References. R. S. Mulliken, *P.R.*, **25**, 259. (1925)†

F. A. Jenkins and A. McKellar, *P.R.*, **42**, 464. (1932)†.

The strong heads are listed below. Intensities, by Mulliken, are for BCl_3 in active nitrogen. Only data for $B^{11}O$ are given.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
6165.4	5	0, 4 Q ₁	4585.7	7	0, 1 R ₂₁	3950.5	4	3, 1 Q ₁
6159.7	5	0, 4 R ₁	4365.9	8	1, 1 Q ₁	3848.7	10	2, 0 Q ₁
5551.5	8	0, 3 Q ₁	4363.4	10	1, 1 R ₁	3847.0	9	2, 0 R ₁
5547.5	7	0, 3 R ₁	4341.9	8	1, 1 R ₂	3829.9	8	2, 0 R ₂
5513.0	5	0, 3 R ₂	4339.4	8	1, 1 R ₂₁	3828.0	6	2, 0 R ₂₁
5043.5	6	0, 2 Q ₁	4250.4	5	0, 0 Q ₁	3679.1	10	3, 0 Q ₁
5040.1	9 ?	0, 2 R ₁	4247.9	4	0, 0 R ₁	3677.8	8	3, 0 R ₁
5011.6	4	0, 2 R ₂	4227.5	4	0, 0 R ₂	3662.3	6	3, 0 R ₂
4746.9	8	1, 2 Q ₁	4145.5	7	2, 1 Q ₁	3660.6	5	3, 0 R ₂₁
4744.0	8	1, 2 R ₁	4143.4	6	2, 1 R ₁	3526.8	7	4, 0 Q ₁
4718.7	5	1, 2 R ₂	4124.1	4	2, 1 R ₂	3525.5	7	4, 0 R ₁
4715.5	5	1, 2 R ₂₁	4037.4	8	1, 0 Q ₁	3511.3	6	4, 0 R ₂
4615.4	10	0, 1 Q ₁	4035.5	7	1, 0 R ₁	3510.0	5	4, 0 R ₂₁
4612.7	10	0, 1 R ₁	4017.1	6	1, 0 R ₂	3389.1	5	5, 0 Q ₁
4588.8	8	0, 1 R ₂	4015.0	5	1, 0 R ₂₁	3387.6	7	5, 0 R ₁
						3374.7	5	5, 0 R ₂

 β SYSTEM, $\lambda\lambda 3645$ – 2120

Occurrence. As for α system.

Appearance. Degraded to the red. Single-headed bands.

Transition. B ${}^2\Sigma \rightarrow {}^2\Sigma$, ground state.

Reference. R. S. Mulliken, *P.R.*, **25**, 259. (1925)†.

The strong bands as obtained by Mulliken in active nitrogen are listed below. The more abundant isotope $B^{11}O$ only is given.

BO (*contd.*)

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
3493.1	4	4, 11	2934.9	9	3, 7	2551.4	9	0, 2
3441.6	6	3, 10	2892.2	10	2, 6	2544.3	7	3, 4
3391.2	5	2, 9	2850.6	8	1, 5	2507.7	6	2, 3
3354.6	5	5, 11	2809.9	8	0, 4	2472.0	5	1, 2
3305.4	8	4, 10	2793.9	7	3, 6	2437.1	10	0, 1
3256.9	9	3, 9	2753.4	9	2, 5	2433.3	6	3, 3
3209.3	7	2, 8	2713.8	10	1, 4	2398.5	10	2, 2
3134.6	6	4, 9	2703.4	4	4, 6	2364.5	8	1, 1
3088.6	9	3, 8	2675.3	8	0, 3	2331.3	7	0, 0
3043.6	9	2, 7	2664.1	4	3, 5	2330.4	6	3, 2
2999.7	7	1, 6	2625.6	6	2, 4	2264.8	6	1, 0
2978.5	6	4, 8	2588.0	8	1, 3	2234.6	4	3, 1
2956.6	6	0, 5	2581.6	4	4, 5	2203.0	4	2, 0

COMBINATION SYSTEM

Occurrence. BCl_3 in active nitrogen containing oxygen.

Appearance. This is a weak system and is usually masked by the overlapping α system. The bands are not clearly degraded, but some are shaded slightly to the violet (see Plate 10).

Transition. $\text{B } ^2\Sigma \rightarrow \text{A } ^2\Pi$, upper state of α system.

Reference. R. S. Mulliken, *P.R.*, **25**, 259. (1925)†.

The following are the strongest bands as listed by Mulliken :—

λ	I	v', v''	λ	I	v', v''
5916.2	1*	0, 2 B_1	5155.5	1	2, 2 B_1
5895.3	$\frac{1}{2}$	1, 3 B_1	4881.2	4*	1, 0 2,1 3,2 A_1
5493.7	$\frac{1}{2}$	2, 3 B_1	4850.9	5	1, 0 2,1 3,2 B_1
5201.1	1	0, 0 A_1	4580.8	1	3, 1 B_1
5189.3	1	2, 2 A_1	4576.5	$\frac{1}{2}$	2, 0 A_1

* Masked by α band.

Note Added in Proof.

N. L. Singh (*Proc. Indian Acad. Sci.*, **A29**, 424 (1949)†) has reported a new system accompanying the boric acid fluctuation bands (see below). They occur when a bead of moistened boric acid is held in a flame and in a spark between two glass tubes. The lower state of this system is identified with the upper state of the β system. Strongest heads degraded to red.

λ	I	v', v''	λ	I	v', v''
5789.5	10	2, 5	5478.5	10	5, 7
5781.0	10	1, 0	5395.2	7	0, 2
5777.1	7	0, 3	5361.2	10	?

The vibrational intensity distribution is rather peculiar.

 B_xO_y

BORIC ACID FLUCTUATION BANDS

References. W. Jevons, *P.R.S.*, **91**, 120. (1915)†.

N. L. Singh, *Curr. Sci.*, **11**, 276. (1942).

B_xO_y (contd.)

Waves of narrow bands are observed when boric acid is introduced into an arc or flame. Band heads of the intercombination system of BO and the new bands of N. L. Singh are present, but there also seems to be structure due probably to a polyatomic emitter, perhaps an oxide of boron such as B₂O₃. Maxima of "waves" $\lambda\lambda 6390, 6200, 6030, 5800, 5450, 5180, 4930, 4710, 4520$. See Plate 10.

BaBr

Occurrence. When barium bromide is introduced into a flame or arc, and in absorption.

Appearance. Marked close sequences; the rotational structure appears to be degraded to the red, while the vibrational structure is degraded to the violet.

Transition. ${}^2\Pi \rightarrow {}^2\Sigma$, ground state.

References. K. Hedfeld, *Z.P.*, **68**, 610. (1931).

O. H. Walters and S. Barratt, *P.R.S.*, **118**, 120. (1928).

The following measurements of the heads of the sequences are by Hedfeld. Intensities I_a and I_e are for absorption and emission in an arc respectively, the former being by Walters and Barratt.

λ	I_a	I_e	Sequence
5415.9	7	4	0, 1 i
5360.1	10	10	0, 0 i
5305.5	6	2	1, 0 i
5260.6	4	2	0, 1 ii
5208.2	10	10	0, 0 ii
5156.4	5	1	1, 0 ii

BaCl**GREEN SYSTEM**

Occurrence. Barium chloride in carbon arc or flame, and in absorption.

Appearance. The system is only slightly degraded, and hence the heads are rather indefinite, the rotational and vibrational structure being degraded in opposite directions for some sequences.

Transition. ${}^2\Pi \rightarrow {}^2\Sigma$, ground state.

References. O. H. Walters and S. Barratt, *P.R.S.*, **118**, 120. (1928)†.

K. Hedfeld, *Z.P.*, **68**, 610. (1931).

A. E. Parker, *P.R.*, **46**, 301. (1934)†.

The analyses proposed by Hedfeld and by Parker differ in some details. The following are probably the most obvious points for measurement under low dispersion. The letters R and V indicate that the sequences are degraded to longer or shorter wave-lengths.

λ	I	Sequence
5320.8 V	3	0, 1 i
5240.5 R	10	0, 0 i
5213 V	1	0, 1 ii
5167 R	2	1, 0 i
5139.2 V	10	0, 0 ii
5136 R		
5066 V	1	1, 0 ii

BaCl (*contd.*)

ULTRA-VIOLET SYSTEMS

Occurrence. In arc.

Reference. A. E. Parker, *P.R.*, **46**, 301. (1934)†.

Longer wave-length system, probably ${}^2\Sigma \rightarrow {}^2\Sigma$, ground state, marked sequences degraded to shorter wave-lengths. The following appear to be the three strongest sequences as seen in the published photographs :—

λ	Sequence
3923.0	0, 0
3876.8	1, 0
3832.0	2, 0

Shorter wave-length system, probably also ${}^2\Sigma \rightarrow {}^2\Sigma$, ground state, degraded to shorter wave-lengths. Strongest sequences :—

λ	Sequence
3691.7	0, 0
3649.9	1, 0

INFRA-RED SYSTEM

Occurrence. In the flame of pyrotechnic compositions.

Appearance. A number of rather close sequences of apparently double-headed bands degraded to longer wave-lengths.

Transition. Probably ${}^2\Pi \rightarrow X^2\Sigma$, ground state.

Reference. R. F. Barrow and D. V. Crawford, *Nature, Lond.*, **157**, 339. (1946).

The violet edges of the two strongest sequences are at 8420.8 and 9098.0 Å. About fifty-five bands have been arranged into a vibrational scheme with $\lambda 8421$ as the (0, 0) band and a further twenty-five bands into another scheme with $\lambda 9098$ as the (0, 0) band.

BaF

Occurrence. When BaF_2 is introduced into carbon arc or a flame. Also in absorption.

References. S. Datta, *P.R.S.*, **99**, 436. (1921)†.

T. E. Nevin, *Proc. Phys. Soc.*, **43**, 554. (1931)†.

F. A. Jenkins and A. Harvey, *P.R.*, **39**, 922. (1932)†.

C. A. Fowler, *P.R.*, **59**, 645. (1941)†.

Eight systems have been obtained in absorption, but only the systems in the green, extreme red and infra-red have been reported in emission.

GREEN SYSTEM, $\lambda\lambda 5139-4842$

Appearance. Degraded to red. Close-marked sequences with "tails." Appearance best given by Datta's photograph.

Transition. C ${}^2\Pi \rightarrow {}^2\Sigma$, ground state.

Strongest heads of sequences. Own estimates of intensity from published photographs.

λ	<i>I</i>	Sequence
5000.6	8	0, 0 Q ₁
4992.1	5	0, 0 R ₁
4950.8	10	0, 0 R ₂

BaF (contd.)**EXTREME RED SYSTEM, $\lambda\lambda 7734-6716$**

Appearance. Degraded to longer wave-lengths. Double-headed bands.

Transition. B $^2\Sigma' \rightarrow ^2\Sigma$, ground state.

R₂ and R₁ heads of strong bands. Intensities on scale of 8.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
7430.8	6	3, 4	6958.7	5	3, 2
7426.9			6955.9		
7142.0	8	1, 1	6935.1	5	2, 1
7138.8			6932.5		
7119.2	8	0, 0			
7116.0					

INFRA-RED SYSTEM, $\lambda\lambda 8738-7862$

Appearance. Degraded to longer wave-lengths. Marked sequences.

Transition. A $^2\Pi \rightarrow ^2\Sigma$, ground state.

Strong bands only. Intensities on scale of 8.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
8618.8	7	2, 2 i Q	8172.3	8	1, 1 ii Q
8595.3	8	1, 1 i Q	8158.7	7	1, 1 ii R
8571.5	7	0, 0 i Q	8151.0	8	0, 0 ii Q
8193.6	8	2, 2 ii Q	8137.0	7	0, 0 ii R

ULTRA-VIOLET SYSTEMS

C. A. Fowler has obtained five additional systems in the ultra-violet in absorption using a vacuum carbon-tube electric furnace. A continuum extending to $\lambda 2450$ from shorter wave-lengths was observed with the furnace at $2,000^\circ$ C.

Transition. D', D $^2\Sigma \leftarrow X^2\Sigma$, ground state.

Appearance. In region $\lambda\lambda 4136-3650$. Degraded violet.

Strongest bands as measured by Jenkins and Harvey :—

λ	<i>I</i>	v', v''
4135.8	4	0, 0 ii
3878.6	3	0, 1 i
3809.9	10	0, 0 i
3804.5	5	1, 1 i
3738.3	6	2, 2 i

Fowler considers that two systems are involved.

Transition. E $^2\Sigma \leftarrow X^2\Sigma$, ground state.

Appearance. In region $\lambda\lambda 3608-3475$. Degraded violet.

Fowler gives the formula for the heads :—

$$v = 28134.1 + 538.4u' - 1.90u'^2 - 468.9u'' + 1.79u''^2.$$

From this the following wave-lengths have been calculated :—

BaF (*contd.*)

λ	I	v', v''
3608.6	3	0, 1
3549.0	10	0, 0
3540.3	3	1, 1
3482.9	5	1, 0
3475.0	2	2, 1

Transition. F $^2\Sigma \leftarrow$ X $^2\Sigma$, ground state.

Appearance. In region $\lambda\lambda 3451-3278$. Degraded violet.

Fowler gives for the heads :—

$$\nu = 24911.3 + 529.9u' - 2.00u'^2 - 469.5u'' + 1.90u''^2.$$

From this the following wave-lengths are obtained :—

λ	I	v', v''
3450.2	4	0, 1
3395.3	10	0, 0
3388.8	8	1, 1
3336.0	7	1, 0
3329.8	8	2, 1
3278.9	2	2, 0

Transition. G $^2\Sigma \leftarrow$ X $^2\Sigma$, ground state.

Appearance. In region $\lambda\lambda 3210-3069$. Degraded violet.

For this system Fowler gives :—

$$\nu = 31451.9 + 510.4u' - 0.83u'^2 - 469.9u'' + 2.08u''^2.$$

This yields :—

λ	I	v', v''
3224.2	—	0, 1
3176.5	10	0, 0
3172.1	6	1, 1
3125.9	6	1, 0
3121.9	7	2, 1
3077.1	2	2, 0

Transition. H $^2\Sigma \leftarrow$ X $^2\Sigma$, ground state.

Appearance. Degraded violet.

Fowler observed the following three heads in the same region as the last system :—

λ	v', v''
3210.7	0, 1
3163.4	0, 0
3113.6	1, 0

BaH

10,000 A. SYSTEM, $^2\Pi \rightarrow ^2\Sigma$

References. W. W. Watson, *P.R.*, 47, 213. (1935).

P. G. Koontz and W. W. Watson, *P.R.*, 48, 937. (1935).

BaH (contd.)

Bands degraded to the red, obtained with an arc between a copper anode and a copper cathode filled with metallic barium in an atmosphere of hydrogen.

v', v''	Heads	
	${}^2\Pi_{3/2} \rightarrow {}^2\Sigma$	${}^2\Pi_{1/2} \rightarrow {}^2\Sigma$
0, 0	R ₂ 10,052	Q ₁ 10,746.4 R ₁ 10,603.3

8924 A. SYSTEM, ${}^2\Sigma \rightarrow {}^2\Sigma$

References. As for above system.

Bands with P and R branches degraded to the red.

v', v''	R ₁ Heads	R ₂ Heads
1, 0	8240	8187
2, 1	8318	8267
0, 0	9017	8924
1, 1	9086	

6700 A. SYSTEM, ${}^2\Pi \rightarrow {}^2\Sigma$

References. G. W. Funke, *Z.P.*, **84**, 610. (1933).

A. Schaafsma, *Z.P.*, **74**, 254. (1932).

W. R. Fredrickson and W. W. Watson, *P.R.*, **39**, 753. (1932).

System of complex bands degraded to the violet obtained in barium arc in hydrogen at reduced pressure.

v', v''	${}^0P_{12}$	P ₁	Heads PQ ₁₂	P ₂	Q _{P₁₂}	Q ₂
0, 1	7481	7423	7422	7222	—	7174
0, 0	6923.5	6850.2	6848.6	6689.5	6635.1	6634.3
1, 1	—	6827.4	6825.8	6665.0	6610.8	6610.0
1, 0	—	—	—	—	6152.4	6151.2

4228 A. SYSTEM, ${}^2\Sigma \rightarrow {}^2\Sigma$

Reference. G. W. Funke and B. Grundström, *Z.P.*, **100**, 293. (1936).

Weak bands degraded to the violet obtained in absorption and emission.

	Origins	P Heads
0, 1	4440	
0, 0	4228	4227.1
1, 1	4201	4202.2
1, 0	4014	
2, 0	4000	

BaI

There is a band system in the green and a weaker system in the ultra-violet.

GREEN SYSTEM

Occurrence. In absorption and in flames.

Appearance. Degraded to shorter wave-lengths.

References. O. H. Walters and S. Barratt, *P.R.S.*, **118**, 120. (1928).

C. M. Olmsted, *Z. wiss. Photogr.* **4**, 255. (1906).

BaI (*contd.*)

Measurements by Walters and Barratt. Intensities I_a and I_f are for absorption and emission in a flame respectively, the latter being by Olmsted.

λ	I_a	I_f
5609.5	10	10
5381.7	10	7
5260	0	
5160	0	

ULTRA-VIOLET BANDS

Occurrence. In absorption.

Appearance. Degraded to shorter wave-lengths.

Bands as observed by Walters and Barratt:—

λ	I
3830	1
3804	2
3778	3
3756	3
3736	1

BaO

Occurrence. When barium salts are introduced into carbon arc or flame.

Appearance. Degraded to longer wave-lengths.

Transition. $^1\Sigma \rightarrow ^1\Sigma$, probably ground state.

Reference. P. C. Mahanti, *Proc. Phys. Soc.*, **46**, 51. (1934)†.

The system extends from $\lambda 7905$ to $\lambda 4269$. Only the strong bands are listed below.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
7097.4	5	0, 4	6039.6	9	1, 1	5349.7	8	4, 0
6782.8	8	0, 3	5976.3	3	0, 0	5214.7	7	5, 0
6493.1	9	0, 2	5864.5	10	2, 1	5086.7	6	6, 0
6291.0	8	1, 2	5805.1	6	1, 0	4965.4	3	7, 0
6224.7	6	0, 1	5701.0	8	3, 1	4850.6	6	8, 0
6165.1	6	3, 3	5644.1	9	2, 0	4680.3	5	11, 1
6102.3	5	2, 2	5492.7	10	3, 0			

BeCl

Occurrence. Beryllium arc in chlorine.

Appearance. Degraded to the red. Marked sequences.

Transition. $^2\Pi \rightarrow ^2\Sigma$, probably ground state.

Reference. W. R. Fredrickson and M. E. Hogan, *P.R.*, **46**, 454. (1934)†.

The following are the outstanding heads; the intensities are our own estimates from the published photographs:—

λ	I	v', v''
3676.8	6	0, 1 R_1
3575.7	9	0, 0 Q_1
3570.9	10	0, 0 R_2
3567.0	10	0, 0 R_1
3559.2	1	0, 0 $^3R_{21}$
3468.3	4	1, 0 R_1

BeF

Occurrence. Beryllium fluoride in carbon arc and in absorption.

Appearance. Degraded to red. Marked sequences.

Transition. ${}^2\Pi \rightarrow {}^2\Sigma$, ground state.

References. W. Jevons, *P.R.S.*, **122**, 211. (1929)†.

F. A. Jenkins, *P.R.*, **35**, 315. (1930)†.

C. A. Fowler, *P.R.*, **59**, 645. (1941)†.

Bands in ultra-violet, $\lambda\lambda 3393$ – 2816 . Strongest bands only listed. The R_2 heads only are given except for (0, 0) band. Own intensities from published photographs.

λ	I	v', v''
3126.1	8	0, 1
3018.0	9	1, 1
3013.0	6	0, 0 Q_1
3009.9	10	0, 0 R_1
3009.6	9	0, 0 R_2
2909.0	7	1, 0
2816.0	3	2, 0

Fowler obtains this system in absorption in a carbon-tube electric furnace of vacuum type at temperatures above $1,500^\circ\text{C}$. A continuum was also observed with maximum somewhere below the short wave-length limit of observation ($\lambda 1950$) which extended to longer wave-lengths with increasing temperature, reaching $\lambda 2900$ at $2,000^\circ\text{C}$.

BeH

References. W. W. Watson, *P.R.*, **32**, 600. (1928).

E. Olsson, *Z.P.*, **73**, 732. (1932).

W. W. Watson and R. F. Humphreys, *P.R.*, **52**, 318. (1937).

4988 A. SYSTEM, ${}^2\Pi \rightarrow {}^2\Sigma$, GROUND STATE

Bands show P, Q and R branches degraded at first to the violet but turning to the red at high values of the rotational quantum number.

Obtained in arc between beryllium poles in hydrogen at a few cms. pressure.

v', v''	Origins	Q Heads
0, 1	5537.2	
1, 2	5507.9	
0, 0	4988.3	4990.8
1, 1	4983.3	4985.7
2, 2	4980.5	4982.8

1960 A. SYSTEM, ${}^2\Pi \rightarrow {}^2\Sigma$, GROUND STATE

Principal feature of this system is a single strong Q branch degraded to short wave-lengths from a head at 1960 A.

Obtained in a hollow cathode of molybdenum and in a beryllium arc in hydrogen.

v', v''	Q Heads
0, 0	1960
1, 1	1956
1, 0	1882

BeH⁺

- References.* W. W. Watson and R. F. Humphreys, *P.R.*, **52**, 318. (1937).
W. W. Watson, *P.R.*, **32**, 600. (1928).

2559 A. SYSTEM, $^1\Sigma \rightarrow ^1\Sigma$, GROUND STATE

An extensive system of singlet bands degraded to the red. Obtained from an arc between beryllium electrodes in hydrogen at low pressures.

v', v''	R Heads
2, 0	2384.6
1, 0	2468.1
0, 0	2559.4
0, 1	2707.4
1, 3	2910.9
0, 3	3039.6
1, 4	3081.8

BeO

There are four systems of bands attributed to beryllium oxide. There is a strong system in the blue-green, a moderately intense system in the far red, and two weak systems in the ultra-violet.

Occurrence. Beryllium salts in carbon arc, arc between beryllium electrodes in air, and in uncondensed spark between Be electrodes.

- References.* E. Bengtsson, *Ark. Mat. Astr. Fys.*, **20A**, No. 28. (1928).
L. Herzberg, *Z.P.*, **84**, 571. (1933)†.
A. Harvey and H. Bell, *Proc. Phys. Soc.*, **47**, 415. (1935).

BLUE-GREEN SYSTEM, $\lambda\lambda 5495-4180$

Reference. A. Lagerqvist and R. Westöö, *Ark. Mat. Astr. Fys.*, **32A**, No. 10. (1945)†.

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

Transition. C $^1\Sigma \rightarrow$ X $^1\Sigma$, ground state.

The following wave-lengths and intensities are for the system as observed with an arc in air between beryllium electrodes.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
5475.7	5	2, 4	4794.9	3	4, 4	4451.7	8	2, 1
5461.7	5	1, 3	4775.7	5	3, 3	4427.3	6	1, 0
5444.9	4	0, 2	4755.0	7	2, 2	4290.9	4	7, 5
5127.7	5	4, 5	4732.6	9	1, 1	4271.0	4	6, 4
5112.4	7	3, 4	4708.6	10	0, 0	4250.1	5	5, 3
5095.1	8	2, 3	4516.5	5	5, 4	4227.9	5	4, 2
5075.7	8	1, 2	4496.3	7	4, 3	4204.6	4	3, 1
5054.4	7	0, 1	4474.7	8	3, 2	4180.1	3	2, 0

RED SYSTEM, $\lambda\lambda 5600-11600$

- References.* L. Herzberg, *Z.P.*, **84**, 571. (1933)†.
A. Lagerqvist and R. Westöö, *Ark. Mat. Astr. Fys.*, **31A**, No. 21. (1945)†.
A. Lagerqvist, *Ark. Mat. Astr. Fys.*, **34B**, No. 23. (1947).

Appearance. Degraded to longer wave-lengths. Double-headed bands, but with R heads rather faint and diffuse.

Transition. B $^1\Pi \rightarrow$ X $^1\Sigma$, ground state.

BeO (contd.)

The origins of the strong bands are listed below. The wave-lengths shorter than 7954 Å. are due to Herzberg and the others to Lagerqvist and Westöö. The v' values are those given by Lagerqvist (1947).

λ_0	v', v''	λ_0	v', v''	λ	I	v', v''
11234.6	1, 1	8468.5	5, 2	7953.3	6	3, 0
10826.6	0, 0	8206.0	4, 1	7324.8	3	4, 0
10344.7	3, 2	7954.5	3, 0	6523.5	4	7, 1
9647.5	1, 0			6344.4	3	6, 0
9002.7	3, 1			6286.9	3	9, 2
8713.4	2, 0			6117.8	3	8, 1

ULTRA-VIOLET BANDS

Reference. A. Lagerqvist, *Dissertation, Uppsala.* (1948).

In the region $\lambda\lambda 2600-3600$ there are many bands ascribed to BeO. They consist in the main of five groups similar to sequences. The structure, however, is complex, possibly consisting of a triplet system and two or more singlet systems. The principal bands, according to Lagerqvist, are as follows:—

λ	I	λ	I	λ	I
3039.0	2	3146.7	3	3368.0	5
3039.5	2	3165.4	2	3371.2	5
3040.0	2	3182.8	2	3375.2	4
3044.4	2	3247.3	3	3377.1	4
3058.4	2	3247.9	3	3378.1	3
3075.2	2	3248.4	3	3379.4	4
3076.2	2	3256.2	3	3382.6	4
3087.0	2	3258.2	3	3384.0	4
3092.8	1	3258.7	3	3495.1	3
3133.8	4	3259.3	3	3498.8	3
3134.1	3	3269.2	3	3500.8	3
3135.3	4	3269.7	3	3506.4	3
3143.3	3	3270.4	3	3515.8	2
3145.6	3	3357.2	2	3519.8	2
3146.2	3	3359.4	2	3661.7	1
		3363.8	5		

The bands are generally degraded to the red, although a few are degraded to the violet. Some of them have been grouped into a system by Bengtsson and others by Harvey and Bell, but there appears to be some doubt as to the reality of these systems. Their main assignments are given below.

BENGTSSON'S ULTRA-VIOLET SYSTEM

Degraded to red. E ($^1\Pi$?) \rightarrow B $^1\Pi$, upper level of red system.

Strong heads:—

λ	I	v', v''
3367.6	2	0, 2
3258.1	3	1, 2
3247.7	3	0, 1
3145.7	3	1, 1
3134.0	3	0, 0

BeO (contd.)**HARVEY AND BELL'S ULTRA-VIOLET SYSTEM**

Degraded to red. D ($^1\Pi$?) \rightarrow B $^1\Pi$, upper level of red system. No intensities given.

The following are probably the strongest bands :—

λ	v', v''
3496.0	0, 1
3371.1	1, 1
3363.7	0, 0
3247.6	1, 0

There is also a head not accounted for at λ 3368.

Bi₂

Four systems of bands have been attributed to diatomic bismuth.

References. G. M. Almy and F. M. Sparks, *P.R.*, **44**, 365. (1933)†.

G. Nakamura and T. Shidei, *Japan Jour. Phys.*, **10**, 11. (1935)†.

VISIBLE SYSTEM, $\lambda\lambda$ 7910–4500

Occurrence. In absorption, in emission (in furnace), and fluorescence.

Appearance. Degraded to the red.

Transition. B \rightarrow A, ground state (probably $^1\Sigma$).

The following are the strongest bands as listed by Nakamura and Shidei, in absorption :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
5679.9	5	3, 3	5453.8	7	6, 1	5293.4	10	9, 0
5625.2	5	3, 2	5415.5	7	7, 1	5258.2	10	10, 0
5531.2	5	4, 1	5365.5	8	7, 0	5224.1	10	11, 0
5491.9	7	5, 1	5329.5	8	8, 0	5190.3	9	12, 0

VIOLET SYSTEM, $\lambda\lambda$ 4200–4000

Occurrence. In absorption at high temperature.

Appearance. Degraded to the red.

Transition. D \leftarrow B, upper state of visible system.

Strongest bands as observed by Almy and Sparks :—

λ	<i>I</i>	v', v''
4150.7	4	0, 3
4128.0	5	0, 2
4105.5	5	0, 1
4064.5	2	1, 0

ULTRA-VIOLET SYSTEM, $\lambda\lambda$ 2900–2600

Occurrence. In absorption. This system appears to come up very easily and has been observed as an impurity, especially with cadmium.

Transition. C \leftarrow A, ground state.

Strong bands as recorded by Almy and Sparks :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
2810.2	5	1, 6	2755.9	4	0, 1
2796.9	7	1, 5	2744.5	6	1, 1
2783.7	5	1, 4	2731.6	9	1, 0
2782.2	4	0, 3	2720.7	7	2, 0
2768.9	7	0, 2	2710.3	5	3, 0

Bi₂ (*contd.*)

FAR ULTRA-VIOLET SYSTEM, $\lambda\lambda 2250-2000$

Weak diffuse bands observed in absorption; probably from ground state. Strong bands as observed by Almy and Sparks, $\lambda\lambda 2205.4, 2197.2, 2188.8, 2180.5, 2172.7, 2148.8, 2142.9,$ and 2135.8 .

BiBr

There are two systems observed in absorption.

$\lambda\lambda 4130-3862$. Bands not clearly degraded either way; strong flutings from 4041 A. getting weaker to shorter wave-lengths.

$\lambda\lambda 5438-4595$. Weaker bands degraded to red. Strongest head at 5246.5 A.

Reference. F. Morgan, *P.R.*, 49, 41. (1936)†.

BiCl

References. F. Morgan, *P.R.*, 49, 41. (1936)†.

S. K. Ray, *Indian J. Phys.*, 16, 35. (1942).†

Occurrence. Two extensive systems have been observed; in emission from the flame surrounding a carbon arc containing BiCl₃, in absorption from the vapour of BiCl₃ at a temperature 800°-1,000° C.

BLUE-GREEN SYSTEM, $\lambda\lambda 5660-4308$

Appearance. Degraded to the red.

Wave-lengths and intensities according to Ray are as follows:—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
5205.7	4	2, 10	4680.1	4	1, 2
5107.4	5	1, 8	4614.4	8	1, 1
5011.6	4	0, 6	4569.9	6	2, 1
4938.4	5	0, 5	4549.9	4	1, 0
4866.4	6	0, 4	4506.7	5	2, 0
4796.3	5	0, 3	4465.3	4	3, 0
4727.6	4	0, 2	4425.9	4	4, 0

ULTRA-VIOLET SYSTEM, $\lambda\lambda 4000-3600$

Appearance. Degraded to the red.

Bands according to Ray:—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3914.3	10	0, 0	3865.0	5	4, 4
3900.3	9	1, 1	3854.4	6	1, 0
3888.4	7	2, 2	3842.1	5	2, 1
3875.8	6	3, 3	3830.9	5	3, 2

In addition to these heads due to BiCl³⁵, some heads due to BiCl³⁷ were also observed.

BiF

SYSTEM A

Occurrence. High-frequency discharge through BiF₃ vapour, and in absorption.

Reference. H. G. Howell, *P.R.S.*, 155, 141. (1936)†.

BiF (*contd.*)

Bands degraded to red. Heads of strongest sequences :—

λ	I	Sequence
4568.2	8	0, 2
4465.5	10	0, 1
4366.7	10	0, 0
4295.8	8	1, 0

SYSTEM B

A weak system in the violet reported as occurring in absorption.

Reference. F. Morgan, *P.R.*, 49, 41. (1936).

SYSTEM C

A triplet system degraded to the red obtained in active nitrogen.

Reference. G. D. Rochester, *P.R.*, 51, 486. (1937).

Strongest heads : $\lambda\lambda 3107, 2743, 2705, 2284$.

BiH

Reference. A. Heimer, *Z.P.*, 95, 328. (1935)†.

Occurrence. The band systems described below have been obtained in the bismuth are in hydrogen at reduced pressure and in discharge tubes containing bismuth vapour and hydrogen.

4698 A. SYSTEM, $^1\Sigma^* \rightarrow ^1\Sigma$

Bands slightly degraded to the violet. Strongest system :—

λ	Origins v', v''	
4361	1, 0	
4697	1, 1	(0, 0) P branch closes up to a weak
4698	0, 0	head near 4736 A. just beyond the
5071	1, 2	strong Bi line 4722 A.
5089	0, 1	

6118 A. SYSTEM, $^1\Sigma^* \rightarrow ^1\Pi$

Bands slightly degraded to the violet.

λ	Origins v', v''	Heads
6118	0, 0	6117.5 Q
6792	1, 2	6792.2 Q
6814	0, 1	6813.5 Q

4842 A. SYSTEM, $^1\Sigma_x \rightarrow ^1\Sigma_y$

Bands slightly degraded to the red. Weak system.

λ	Origins v', v''
4842	0, 0
5171	0, 1

BiI

References. F. Morgan, *P.R.*, **49**, 41. (1936)†.

P. T. Rao, *Curr. Sci.*, **18**, 42. (1949).

Bands $\lambda\lambda 4308-4164$ have been observed in emission in a high frequency discharge and in absorption ; some are degraded in each direction ; the (0, 0) band is at 4271.2.

A weaker system 5900-5650 A. is reported in emission from the high-frequency discharge.

BiO

References. C. Ghosh, *Z.P.*, **86**, 241. (1933)†.

A. K. Sen Gupta, *Indian J. Phys.*, **18**, 182. (1945).

Occurrence. In flames and arcs containing bismuth salts.

Appearance. Degraded to the red.

Ghosh observed bands over the range $\lambda\lambda 6617-4316$, which he divided into four systems, A, B, C and D. Sen Gupta finds that many of these bands are identical with those found by Ray for BiCl. He attributes the following bands, which do not show the isotope effect to be expected for a chloride and were not obtained by Ray, to BiO :—

λ	v', v''	λ	v', v''	λ	v', v''
6710.3	1, 1	6299.3	3, 1	5867.9	4, 0
6621.5	0, 0	6217.6	2, 0	5786.1	6, 1
6583.0	3, 2	6116.7	4, 1	5712.0	5, 0
6495.8	2, 1	6036.9	3, 0	5638.5	7, 1
6411.7	1, 0	6022.3	6, 2	5563.9	6, 0
6380.0	4, 2	5943.5	5, 1		

Br₂**MAIN (ABSORPTION) SYSTEM**

Occurrence. This system occurs readily in absorption by bromine vapour. It has also been observed by Uchida in emission from the heated vapour, by Kitagawa in the flame of bromine burning in hydrogen and by Vaidya in the flame of ethyl bromide.

Appearance. Degraded to the red. Very closely spaced bands extending from 5100 A. to the near infra-red. In absorption there is a continuum in the blue (commencing at the short wave limit of the band system).

References. H. Kuhn, *Z.P.*, **39**, 77. (1926).

W. G. Brown, *P.R.*, **38**, 1179. (1931); *P.R.*, **39**, 777. (1932).

O. Darbyshire, *P.R.S.*, **159**, 93. (1937)†.

Y. Uchida, *Inst. Phys. Chem. Res. Tokyo Sci. Papers*, No. 651, 71. (1936).

T. Kitagawa, *Proc. Imp. Acad. Tokyo*, **11**, 262. (1935).

W. M. Vaidya, *Proc. Indian Acad. Sci.*, **7A**, 321. (1938).

A full table of wave-lengths of the absorption bands without intensities is given by Kuhn. The following are the wave-lengths (averaged from the above references) of the bands which have been observed in emission by most of the above authors. Most of these bands occur in absorption also.

$\lambda\lambda 6546, 6472, 6415, 6364, 6342, 6312, 6291, 6263, 6239, 6220, 6189, 6168, 6120, 6071, 5957, 5942, 5864, 5826, 5752, 5725, 5603, 5588.$

Br₂ (*contd.*)EMISSION BANDS, $\lambda\lambda 6700-5000$

Occurrence. Observed by Uchida and Ota in an uncondensed discharge through bromine vapour.

Appearance. Degraded to longer wave-lengths.

Reference. Y. Uchida and Y. Ota, *Japan. J. Phys.*, 5, 59. (1928)†.

The bands have been tentatively arranged into two systems. The following are the wave-lengths of the strongest bands with our estimates of the intensities made from the published photograph :—

λ	<i>I</i>	λ	<i>I</i>	λ	<i>I</i>	λ	<i>I</i>
6646	3	6392.8	6	6027.8	8	5586.1	9
6579.0	4	6372.1	5	6004.6	10	5532.4	7
6540.7	4	6332.8	6	5945.7	9	5529.2	6
6519.7	4	6282.0	6	5880.6	10	5428.6	4
6475.6	7	6217.0	7	5819.7	9	5382.6	4
6455.1	7	6144.8	8	5758.3	10	5134.2	3
6435.9	8	6083.1	8	5699.9	10	5100.7	3
6421.2	5	6074.6	8	5644.3	9		

EMISSION BANDS, $\lambda\lambda 4200-2000$

Occurrence. Discharge tube containing bromine.

Appearance. Diffuse.

Reference. P. Venkateswarlu, *Proc. Indian Acad. Sci.*, 25A, 138. (1947)†.

Wave-lengths and intensities are given for sixty-seven diffuse maxima.

Strongest :—

λ	<i>I</i>	λ	<i>I</i>	λ	<i>I</i>	λ	<i>I</i>
4224.5	4	3336.6	10	2753.6	8	2526.9	6
3932.5	3	2923.8	8	2732.4	7	2510.9	6
3597.8	4	2900.4	10*	2709.8	7	2494.2	6
3549.4	10	2872.5	8	2638.9	6	2478.8	7
3366.8	6	2780.6	7	2623.1	6		

* This band, around 2900 A., has been observed by Coleman and Gaydon in flames containing Br₂.

BrF

Reference. P. H. Brodersen and H. J. Schumacher, *Z. Naturforsch.*, 2a, 358. (1947)†.

Single-headed bands degraded to the red in absorption. The following appear to be the strongest :—

λ	<i>v', v''</i>	λ	<i>v', v''</i>	λ	<i>v', v''</i>
5130.4	3, 1	4987.3	5, 1	4890.8	4, 0
5055.3	4, 1	4961.0	3, 0	4827.4	5, 0
5037.9	2, 0	4929.9	6, 1	4773.1	6, 0

BrO

ETHYL BROMIDE FLAME BANDS

Occurrence. In flame of ethyl bromide and when bromine is added to oxy-hydrogen flame. The bands occur most strongly in the region just above the inner cone of the flame.

BrO (contd.)

Appearance. Degraded to longer wave-lengths. The $v' = 0$ progression is relatively conspicuous.

References. W. M. Vaidya, *Indian Acad. Sci. Proc.*, 7A, 321. (1938).
E. H. Coleman and A. G. Gaydon, *Disc. Faraday Soc.*, 2, 166. (1947)†.

The following measurements and analysis from Coleman and Gaydon :—

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
4856	2	1, 7	4349	4	2, 4	4109	4	2, 2
4817	3	0, 6	4270	10	0, 2	4069	5	1, 1
4673	8	0, 5	4225	2	2, 3	4029	3	0, 0
4533	10	0, 4	4186	3	1, 2	3999	3	2, 1
4398	10	0, 3	4147	6	0, 1	3958	3	1, 0

C₂

There are three strong band systems attributed to this molecule, the *Swan* bands sometimes known as the First Positive bands of carbon, Fowler's *High Pressure* system, and *Deslandres and d'Azambuja's* spark system. Weaker systems have been observed by *Mulliken*, by *Fox and Herzberg* and by *Phillips*.

SWAN SYSTEM

Occurrence. These bands are of very frequent occurrence in sources containing carbon. They are especially strongly developed in the green part of the roaring flame of a Bunsen or Meeker burner, and in vacuum tube discharges of high current density through hydrocarbon vapours. They have also been observed in active nitrogen, in discharge tubes containing helium and a trace of CO, and in the electric furnace. They have also been obtained in absorption during the thermal decomposition of carbon suboxide, C₃O₂, by A. Klemenc, R. Wechberg and G. Wagner (*Z. Elektrochem.*, 40, 488. (1934)).

Appearance. Degraded to violet. Single-headed. Sequences well marked. See Plate 9.

Transition. $^3\Pi \rightarrow ^3\Pi$, ground state.

References. R. C. Johnson, *Phil. Trans. Roy. Soc. A.*, 226, 157. (1927).

W. Jevons, *Report on Band Spectra of Diatomic Molecules*, The Physical Society, 1932.

λ	I	v', v''	λ	I	v', v''
6677.3	1	2, 5	5501.9	4	3, 4
6599.2	1	3, 6	5470.3	2	4, 5
6533.7	2	4, 7	5165.2	10	0, 0
6480.5	2	5, 8	5129.3	6	1, 1
6442.3	2	6, 9	5097.7	1	2, 2
6191.2	3	0, 2	4737.1	9	1, 0
6122.1	4	1, 3	4715.2	8	2, 1
6059.7	3	2, 4	4697.6	7	3, 2
6004.9	3	3, 5	4684.8	4	4, 3
5958.7	2	4, 6	4678.6	2	5, 4
5923.4	1	5, 7	4668.7	1	6, 5
5635.5	8	0, 1	4382.5	2	2, 0
5585.5	8	1, 2	4371.4	4	3, 1
5540.7	6	2, 3	4365.2	5	4, 2

C_2 (contd.)

J. G. Phillips (*Astrophys. J.*, **108**, 434 (1948)) has observed some "tail bands." The following heads are degraded to the red, $\lambda\lambda 4996.7$ (13, 12), 4911.0 (12, 11), 4836.1 (11, 10), 4770.1 (10, 9), and there are headless bands with origins at $\lambda\lambda 4734$ (9, 8) and 4395 (8, 6).

High Pressure Bands

Occurrence. In condensed discharge through CO at relatively high pressure (10 to 100 mm.).

Appearance. Degraded to violet. Appear double-headed with small dispersion, but under larger dispersion the shorter wave-length heads become less definite owing to resolution into line structure.

Transition. $^3\Pi \rightarrow ^3\Pi$, ground state.

References. R. C. Johnson and R. K. Asundi, *P.R.S.*, **124**, 668. (1929).

A. Fowler, *Mon. Not. R. Astr. Soc.*, **70**, 484. (1910)†.

J. G. Fox and G. Herzberg, *P.R.*, **52**, 638. (1937).

G. Herzberg, *P.R.*, **70**, 762. (1946).

In the following table the longer wave-length heads are those given by Johnson and Asundi and the shorter wave-length heads, where given, are by Fowler. Fox and Herzberg suggest that the High Pressure Bands of C_2 are Swan Bands corresponding to $v' = 6$. They may appear without the ordinary Swan Bands, and Herzberg puts forward inverse predissociation as a possible explanation of this behaviour. Intensities on a scale of 15.

λ	I	v', v''	λ	I	v', v''
7852.5	4	6, 11	4680.2	15	6, 5
—			4663	6	
7083.2	6	6, 10	4368.8	7	6, 4
—			4353	3	
6442.3	8	6, 9	4093	2	6, 3
6420	4		—		
5899.3	10	6, 8	3619.5	1	6, 1
5878	5		—		
5434.9	5	6, 7	3419	1	6, 0
5413	2		—		
5030	2	6, 6			
5015	1				

DESLANDRES-D'AZAMBUJA'S SYSTEM

Occurrence. Condensed discharge through CO, CO_2 , or C_2H_2 , or through argon containing hydrogen between carbon electrodes. In spark through liquid alcohol. In carbon arc in hydrogen running under high temperature conditions.

Appearance. Degraded to shorter wave-lengths.

Transition. $^1\Pi \rightarrow ^1\Pi$. The position of these levels relative to the $^3\Pi$ ground level is unknown.

C_2 (contd.)

References. R. C. Johnson, *Nature, Lond.*, **125**, 89. (1930).
G. H. Dieke and W. Lochte-Holtgreven, *Z.P.*, **62**, 767. (1930).

λ	I	v', v''	λ	I	v', v''
4102.3	9	0, 1	3607.3	8	1, 0
4068.1	6	1, 2	3592.9	7	2, 1
4041.8	3	2, 3	3587.6	7	3, 2
4026.9	1	3, 4	3399.7	5	2, 0
3852.2	10	0, 0	3398.1	5	3, 1
3825.6	5	1, 1			

Tail Bands. Herzberg and Sutton obtained the following tail bands for the Deslandres-d'Azambuja system from an uncondensed discharge through helium containing benzene vapour:—

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

They are included among other bands due to C_2 previously reported by Fox and Herzberg (see below).

Reference. G. Herzberg and R. B. Sutton, *Canad. J. Res.*, **40**, 74. (1940).

FOX-HERZBERG SYSTEM

Occurrence. Weakly condensed discharge through helium containing benzene vapour.

Appearance. Shaded to red.

Transition. ${}^3\Pi \rightarrow {}^3\Pi$, ground state.

Reference. J. G. Fox and G. Herzberg, *P.R.*, **52**, 638. (1937).

J. G. Phillips, *Astrophys. J.*, **110**, 73. (1949)†.

λ	v', v''	λ	v', v''	λ	v', v''
*3283	0, 6	2772.1	1, 3	2527.9	3, 2
*3129	0, 5	2731.5	0, 2	2486.3	2, 0
2996.4	1, 4	2698.8	2, 3	2429.9	3, 0
**2987	0, 4	2656.3	1, 2	2378.2	4, 0
**2855	0, 3	2589.0	2, 2		

* Probably fairly strong.

** Strong band.

MULLIKEN'S SYSTEM

Occurrence. In emission in carbon arc, in oxy-acetylene flame and in discharge tubes containing hydrocarbons.

References. R. S. Mulliken, *Z. Elektrochem.*, **36**, 603. (1930).

J. G. Fox and G. Herzberg, *P.R.*, **52**, 638. (1937).

Headless ${}^1\Sigma \rightarrow {}^1\Sigma$ band at 2313.7 Å. Weaker band at 2421.5 may be (0, 1) band of same system. Intensity maximum at about 2325 Å.

PHILLIPS NEAR INFRA-RED SYSTEM

Occurrence. In heavy current discharge.

Transition. ${}^1\Pi \rightarrow {}^1\Sigma$. The levels involved are the lower states of the Deslandres-d'Azambuja and the Mulliken systems.

Reference. J. G. Phillips, *Astrophys. J.*, **107**, 389. (1948)†.

The bands are degraded to longer wave-lengths. Heads $\lambda\lambda$ 8980.5, 8750.8, 8108.2, 7907.7, 7714.6.

C₂ (*contd.*)**OTHER BANDS**

Reported by Fox and Herzberg (*P.R.*, 52, 638, 1937) and possibly due to C₂.
 Degraded red, $\lambda\lambda$ 4496.9, 4339.6, 4324.4, 4147.8, 3670.8, 3560.7, 3506.6, 3384.4.
 Degraded violet, $\lambda\lambda$ 2218.5, 2216.6, 2143.0.

CCI

Occurrence. Uncondensed discharge through flowing CCl₄ vapour and in flames.
Reference. R. K. Asundi and S. M. Karim, *Proc. Indian Acad. Sci.*, 6A, 328. (1937).

CONTINUOUS BANDS

Long λ limit	Maximum	Short λ limit	Intensity
5850	4600	4000	Strong
4000	3348	3260	Moderate
3260	3070	3000	Strong
2700	2580	2500	Strong
2500	2430	2380	Weak
2380	2300 ?	2250	Weak

BANDS DEGRADED TO SHORTER WAVE-LENGTHS

Transition. Perhaps ${}^2\Sigma \rightarrow {}^2\Pi$, ground state.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
2862.0	0	0, 1	2788.3	8	1, 1
2856.8	4		2777.6	8	
2849.4	4				
2845.8	4		2786.6	5	2, 2 ?
2795.9	6	0, 0	2724.3	0	1, 0
2789.8	8		2713.4	0	
2782.3	8				
2778.8	6				

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 A., 3900 A. and 3143 A. respectively. Their intensities decrease in the order in which they are given, the third usually being much the weakest.

4300 A. SYSTEM

Occurrence. In sources where carbon and hydrogen are present together such as flames of hydrocarbons, the carbon arc 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.

CH (contd.)

Appearance. Usually the (0, 0) band is the only one to appear unless the exposure is very great. This shows a strong broad Q head degraded to the violet and a P branch of open structure which can usually be traced from the Q head to about λ 4384. Both branches consist of narrow doublets. See Plate 4.

Transition. ${}^2\Delta \rightarrow {}^2\Pi$, ground state.

References. C. W. Raffety, *Phil. Mag.*, **32**, 546. (1916)†.

H. Grenat, *C.R. Acad. Sci. Paris*, **192**, 1553. (1931).

W. M. Vaidya, *Proc. Nat. Inst. Sci. India*, **7**, 90. (1941)†.

v', v''	Q Heads	I	R Heads	I
0, 1	4890.0	2	4940	1
0, 0	4315.0	3	4384	3
	4312.5	10		

3900 A. SYSTEM

Occurrence. Similar to the 4300 A. system.

Appearance. The (0, 0) band is of very open structure, degraded to the red. The Q head is rather broad while the R head is sharp and line-like. Other members of the system are obtained a little more readily than in the case of the 4300 A. system. See Plate 4.

Transition. ${}^2\Sigma \rightarrow {}^2\Pi$, ground state.

References. As for 4300 A. system.

v', v''	λ	Heads		λ	R	I
		Q	I			
1, 1	4025.3	1				
0, 0	3889.0	4		3871.1	5	
1, 0	3628	1				

3143 A. SYSTEM

Occurrence. Similar to the above, but favoured by a higher temperature.

Appearance. The (0, 0) and (1, 1) bands have been reported. The branches consist of doublets. The Q branches are at first degraded to the violet, then at the sixteenth member form a second head and turn to the red. This last head is the most intense.

Transition. ${}^2\Sigma \rightarrow {}^2\Pi$, ground state.

References. T. Hori, *Z.P.*, **59**, 91. (1930)†.

T. Heimer, *Z.P.*, **78**, 771. (1932).

v', v''	Q Heads		
1, 1	3156.6		
0, 0	3144.9	3144.1	3143.4

CH⁺

Occurrence. Discharge through helium with a trace of benzene.

Appearance. Single P, Q and R branches degraded to the red.

Transition. ${}^1\Pi \rightarrow {}^1\Sigma$, ground state.

Reference. A. E. Douglas and G. Herzberg, *Canad. J. Res.*, **A20**, 71. (1942)†.

CH⁺ (*contd.*)

v', v''	λ R Head	λ Q (1)
0, 1	4775.9	4794.0
0, 0	4225.3	4237.6
1, 0	3954.4	3962.1
2, 0	3743.7	3749.2

Absorption lines at $\lambda\lambda$ 4232.58, 3957.72 and 3745.33 in the spectra of certain stars have been identified with the R(0) lines of the (0, 0), (1, 0) and (2, 0) bands of CH⁺ and attributed to absorption in interstellar space.

CH₂ ?**THE λ 4050 COMET-HEAD GROUP**

Occurrence. This group was first observed in spectra of heads of comets. Herzberg identified them with bands obtained from discharges in very rapidly flowing CH₄ and gave reasons for attributing them to CH₂. R. Herman also obtained them with discharges between carbon electrodes in xenon containing hydrogen. Monfils and Rosen have produced them with a graphite hollow cathode containing pure hydrogen or hydrocarbons or deuterium. Since no isotope displacements were observed in changing from hydrogen to deuterium Monfils and Rosen doubt the assignment to CH₂.

Appearance. Group of diffuse narrow bands.

References. G. Herzberg, *Astrophys. J.*, **96**, 314. (1942)†.

P. Swings, *Mon. Not. R. Astr. Soc.*, **103**, 92. (1943).

R. Herman, *Comité National Français d'Astronomie Communication et Memoires.* (1948)†.

A. Monfils and B. Rosen, *Nature, Lond.*, **164**, 713. (1949).

Swings gives the following wave-lengths and intensities for the *lines* of the group as observed in comets :—

λ	I	λ	I	λ	I
4075.0	?	4051.5	10	4019.2	4
4073.5	3	4043.5	4	4013.2	3
4069.3	2	4042.1	5	4002.2	1
4064.3	1	4039.1	5	3992.6	2
4054.2	1	4033.2	1	3987.2	2

C₂H₂, Acetylene**ULTRA-VIOLET ABSORPTION**

Reference. G. B. Kistiakowsky, *P.R.*, **37**, 276. (1931).

There is a relatively weak system of absorption bands around 2300 Å. This is superposed on weak continuous absorption below 2350 Å. The bands are degraded to the red. In some cases there are two or more close heads; in the following table only the first heads of each group are listed.

λ	I	λ	I	λ	I	λ	I	λ	I
2377.0	1	2343.4	2	2314.2	3	2288.3	10	2255.7	3
2371.4	1	2340.5	3	2309.3	1	2285.3	10	2249.5	3
2355.9	1	2326.6	1	2300.5	2	2266.9	5	2247.8	3
2352.0	1	2320.1	5	2291.9	2	2260.7	3	2245.8	3

C₂H₂, Acetylene (contd.)

INFRA-RED ABSORPTION (VIBRATION-ROTATION SPECTRUM)

Reference. K. Hedfeld and R. Mecke, *Z.P.*, **64**, 151. (1930)†.

Acetylene shows an absorption band with origin at 7887 Å., and maxima of intensity at 7874 and 7901 Å. There are also bands, which are presumably weaker, at 7956 and 8622 Å.

C₆H₆, Benzene

EMISSION SPECTRUM

Occurrence. The bands are most clearly produced by a Tesla Coil discharge through benzene vapour, but can also be observed in an ordinary uncondensed discharge through flowing benzene vapour.

Appearance. Degraded to the red. Evenly spaced groups of bands similar in general appearance to the sequences of diatomic molecules.

References. J. B. Austin and I. A. Black, *P.R.*, **35**, 452. (1934)†.

R. K. Asundi and M. R. Padhye, *Nature, Lond.*, **156**, 368. (1945).

Austin and Black have published a good photograph and a long list of wavelengths, but no estimates of intensities; the following are probably the outstanding heads, the intensities being our estimates from the photograph:—

λ	I	λ	I	λ	I	λ	I
2903.7	4	2822.6	4	2751.2	7	2673.5	5
2900.6	3	2820.0	4	2739.1	10	*2667.4	10
*2898.1	4	*2812.3	7	*2736.5	8	2657.5	3
2837.9	6	2810.6	3	2689.2	6	2613.6	8
2832.9	3	2764.9	5	2684.6	6	2608.7	6
2828.1	5	2757.7	4	2678.6	9	*2602.6	9

* Head of group.

ABSORPTION SPECTRUM

Occurrence. Absorption by benzene vapour. The bands are also observed in absorption by liquid benzene and in solution.

Appearance. Degraded to the red. Evenly spaced groups of bands, usually three strong bands to each group. In solution the bands are shifted to the red and are less sharp. See Plate 10.

Reference. V. Henri, *J. Phys. Radium*, **3**, 18. (1922).

The following are the principal heads as observed by Henri for the vapour; no intensities are recorded and the estimates given below are our own from Henri's description and from the extinction coefficients in solution:—

λ	I	λ	I	λ	I	λ	I
2667.1	1	2539.0		2428.5		*2363.5	3
2602.9		*2528.6	10	2425.3		2324.4	
2599.8		2483.7		*2415.9	5	2313.1	
*2589.0	9	2480.8		2375.2		2275.2	
2541.7		*2471.0	9	2372.5			

* Head of group.

C₆H₆, Benzene (*contd.*)

The following are the approximate wave-lengths of the heads of the strongest groups of absorption bands in various solvents, etc. :—

H ₂ O	2674	2594	2535	2477	2426	2372
CH ₃ OH	2682	2605	2543	2484	2430	2375
C ₂ H ₅ OH	2684	2606	2545	2485	2433	2377
Hexane	2686	2607	2547	2487	2435	2378
CCl ₄	—	2618	2558	2498	2439	—
Liquid benzene	2691	2611	2552	2492	2436	2384
Benzene vapour	2667	2589	2528	2471	2416	2363

FLUORESCENCE SPECTRUM

Occurrence. Fluorescence of benzene in solution.

Reference. V. Henri (see above).

This system and the emission spectrum and also the absorption spectrum are apparently all parts of the same system, the red end appearing stronger in emission and the shorter wave-length bands in absorption. The fluorescence spectrum is similar to the emission spectrum apart from the shift to longer wave-lengths due to the action of the solvent. The following are the heads as recorded by Henri for solution in pentane :—

λ	I	λ	I
3005	7	2766	10
2917	8	2701	8
2847	9	2659	6

BENZENE DERIVATIVES

Most simple derivatives of benzene show a banded absorption spectrum in the region 2600–2400 Å. and a Tesla luminescence spectrum of similar type to that of benzene. In addition, McVicker, Marsh and Stewart have observed a system of bands in the blue; these bands are produced by several benzene derivatives (toluene, ethyl benzene, benzyl alcohol, benzaldehyde, ethyl benzoate), but not by benzene itself or phenol. The emitter of these bands is uncertain, but may be C₆H₅C≡ or a similar radical.

Occurrence. Tesla coil discharge through benzaldehyde vapour or certain other benzene derivatives.

Reference. W. H. McVicker, J. K. Marsh, A. W. Stewart, *J. Chem. Soc.*, **123**, 2147. (1923)†.

The bands form three strong and one weak group; they are probably shaded to the red. The following are the approximate wave-lengths of the shorter wave-length edges of the strong bands; the intensities are our own estimates from the published photograph :—

λ	I	λ	I
4990	?	4255	10
4645	4	4237	5
4600	7	4010	5
4595	3	3970	9
4307	6	3940	3

CHO

HYDROCARBON FLAME BANDS (ETHYLENE FLAME BANDS)

Occurrence. The bands have been observed most strongly in the inner cone of the flame of burning ethylene, but they also occur in the flames of burning ether, benzene, phenol, toluene and many aromatic compounds and weakly in the inner cone of a Bunsen burner. Also during excitation of formaldehyde by far ultra-violet light.

Appearance. Degraded to the red. Rather diffuse single-headed bands. See Plate 9.

Reference. W. M. Vaidya, *P.R.S.*, 147, 513. (1934)†.

The bands are attributed to the radical HCO by Vaidya; they have been classed into two systems, A and B, which appear under slightly different experimental conditions; the bands have been arranged into a scheme similar to that for a diatomic molecule. The strong bands of both systems as given by Vaidya are reproduced here :—

SYSTEM A

λ	I	λ	I	λ	I
4092.0	3	3417.4	3	2797.1	5
3824.9	4	3377.4	10	2751.5	4
3730.5	5	3299.2	10	2716.0	5
3635.6	3	3014.8	8	2658.8	4
3588.6	8	2948.2	7	2618.0	3
3502.7	8	2858.0	6	2585.5	3

SYSTEM B

λ	I	λ	I
3802.7	2	3359.0	5
3697.7	4	3001.5	2
3569.2	3	2780.4	2
3472.5	5	2704.5	1

CHOOH, Formic Acid

Reference. B. Sugarman, *Proc. Phys. Soc.*, 55, 429. (1943)†.

The absorption spectrum shows a number of diffuse bands without well-defined heads in the range $\lambda\lambda 2600-2260$. Below $\lambda 2260$ the absorption becomes continuous at least to $\lambda 1900$.

Centres of bands :—

λ	I	λ	I	λ	I
2500.0	1	2394.7	5	2340.3	10
2461.2	4	2391.2	4	2335.8	6
2443.4	4	2382.2	9	2325.2	9
2420.8	6	2377.2	6	2318.9	7
2414.3	4	2372.8	5	2302.9	8
2408.4	4	2361.5	9	2284.9	10
2398.3	10	2354.0	6	2273.3	5
		2350.7	3		

CH₂O, Formaldehyde

ABSORPTION SPECTRUM

Reference. V. Henri and S. A. Schou, *Z.P.*, **49**, 774. (1928)†.

The absorption spectrum of formaldehyde vapour is very complex and not readily identified except by comparison of spectrograms. Henri and Schou give excellent reproductions of the spectrum; the following measurements and intensity estimates are based on these. Some of the bands are degraded to the red, and when there is a definite edge this is given. The wave-length of the strongest line of the structure is also given where available. See Plate 10.

Limits of Strong Part of Band.	Strongest Line.	Edge (Deg. R)	Int.
3456-3418	3430.9	—	2
3416-3377	3389.3	3387	4
3306-3288	3294.7	3288	6
3274-3249	3260.4	—	7
3215-3198	3203.3	3198	3
3185-3164	3170.4	3164	9
3160-3133	3143.4	—	8
3102-3082	3088.7	—	5
—	—	3057	3
3075-3049	3054.2	3051	5
3048-3028	3035.8	3033 ?	7
2985-2974	2978.9	2978.9	6
2954-2948	2951.9	2948	6
2945-2931	2935.0	2931	10
2898-2874	—	2874 ?	6
2855-2835	—	2839	9
2801-2787	—	2787	7
2766-2756	—	2756	5
2756-2747	—	2747	5
2716-2706	—	—	3
2675-2667	—	2667	1

EMELÉUS'S COOL FLAME SPECTRUM; FORMALDEHYDE FLUORESCENCE

Occurrence. In the cool flame of ether, acetaldehyde, hexane and other organic substances. Also in fluorescence by formaldehyde and Tesla discharge.

Appearance. A number of narrow approximately equally spaced bands; probably degraded to the red. See Plate 8.

References. G. Herzberg and K. Franz, *Z. Phys.*, **76**, 720. (1931).

S. Gradstein, *Z. phys. Chem.*, **22B**, 384. (1933).

V. Kondratjew, *Acta Physicochim.*, *U.R.S.S.*, **4**, 556. (1936).

H. J. Emeléus, *J. Chem. Soc.*, p. 2948. (1926)†.

The identity of the cool flame bands with the fluorescence was established by Pearse. The following are the wave-lengths of the maxima of the bands (from Herzberg and Franz after Kondratjew) with our estimates of intensity in the cool flame.

CH₂O, Formaldehyde (contd.)

λ	I	λ	I	λ	I
5107	0	4447.6	7	3959.6	10
4942	1	4359.9	8	3855.5	9
4821	3	4242.8	9	3767	3
4707.1	5	4129.2	8	3706.3	10
4566.8	7	4053.3	5	(3540)	4
				(3410)	2

C₂H₄O, Acetaldehyde

Occurrence. Absorption by acetaldehyde vapour.

Appearance. Strong absorption with maximum at 2900 A., with a complex structure of discrete bands from 3400 A. to 3200 A., after which they become diffuse and finally merge into continuum around 2800 A. Some of the bands appear to be shaded to the red.

Reference. S. A. Schou, *Jour. de Chim. Phys.*, **26**, 27. (1929).

The following are the limits of the outstanding bands as taken from Schou's list :—

λ	I	λ	I	λ	I	λ	I
3399.3	3	3320.0	6	3254.4	6	3207.3	6
3381.1		3314.7		3247.3		3202.0	
3376.6	2	3305.1	4	3241.1	6	3199.0	7
3363.0		3299.9		3234.1		3196.1	
3359.0	4	3296.2	6	3231.4	5	3190.9	9
3344.5		3289.9		3228.7		3180.2	
3341.7	3	3281.3	5	3222.1	5	3177.5	8
3328.9		3274.4		3216.9		3172.2	
		3267.6	7	3215.6	6	Diffuse bands extend to 2800, after which absorption is continuous.	
		3258.3		3212.7			

C₂H₅CHO, Propionaldehyde

Occurrence. Absorption by the vapour.

Appearance. Complex system of diffuse bands from 3400 A., merging into a continuum at 3250 A., this continuum extending to about 2500 A.

Reference. S. A. Schou, *Jour. de Chim. Phys.*, **26**, 39. (1929).

The following are the limits of the strongest bands :—

λ	I	λ	I	λ	I
3370.8	4	3322.0	8	3276.7	8
3363.9		3316.4		3272.3	
3343.6	5	3298.1	9	3269.0	7
3339.6		3294.2		3262.0	
3336.1	6	3288.7	8	3258.7	8
3332.3		3284.8		3248.9	
3331.4	6				
3324.9					

C₃H₆O, Acetone

Occurrence. Absorption by the vapour.

Reference. E. J. Bowen and H. W. Thompson, *Nature, Lond.*, **133**, 571. (1934).

Acetone shows continuous absorption from 3200 Å. to 2400 Å., with a maximum at about 2800 Å. At low pressure this continuum breaks up into four groups each of about 25 diffuse bands; these groups have maxima at 3150, 2900, 2710 and 2570 Å.

C₆H₅CHO, Benzaldehyde

Occurrence. Absorption by benzaldehyde vapour.

Reference. M. Hemptinne, *J. Phys. Radium*, **9**, 357. (1928)†.

The following maxima of the narrow headless bands are taken from Hemptinne's published spectrogram. Intensities (on a scale of 5) are our estimates from the spectrogram, and some of the wave-lengths are also taken from this.

λ	I	λ	I	λ	I
2851	1	2766*	4	2716	1
2841	5	2746	3	2709	2
2806	2	2735	3	2696	2
2777	2	2726	1	2677	2

* A misprint in the wave-length recorded has been corrected.

CHOCHO, Glyoxal

References. H. W. Thompson, *Trans. Faraday Soc.*, **36**, 988. (1940).

A. G. Gaydon, *Trans. Faraday Soc.*, **43**, 36. (1947)†.

Characteristic narrow bands, mostly degraded to the violet, are shown by glyoxal vapour in absorption, in emission in a Tesla discharge, and in fluorescence. The intensities I_a , I_t and I_f are for these three sources respectively. Wave-lengths by Gaydon.

λ	I_a	I_t	I	λ	I_a	I_t	I_f	λ	I_a	I_t	I_f
5209	—	7	3	4784	—	6	(7)	4605	3	5	7
4946	—	5	5	4777	1	9	10	4555	10	10	8
4906	—	5	6	4752	—	6	7	4532	7	7	5
4793	—	5	(7)	4670	2	7	7	4404	6	1	6
								4280	8	0	3

CH₃NO₂, Methyl Nitrite

Occurrence. Absorption by vapour.

Appearance. Diffuse bands in near ultra-violet, and continuous absorption further in ultra-violet.

References. H. W. Thompson and C. H. Purkis, *Trans. Faraday Soc.*, **32**, pp. 674 and 1466. (1936)†.

Strongest bands, with our estimates of intensity from published photograph in brackets:—

$\lambda\lambda$ 3651 (4), 3508 (9), 3390.2 (10), 3284.1 (8), 3187.1 (5).

C₂H₅NO₂, Ethyl nitrite

Occurrence. Absorption by vapour.

Appearance. Diffuse bands in near ultra-violet and continuous absorption in further ultra-violet.

References. See methyl nitrite.

Strong bands, with own estimates of intensities from published photograph given in brackets :—

λλ3689 (4), 3549 (10), 3429 (8), 3316 (4), 3221 (2).

CN

There are two systems of bands due to CN known as the cyanogen Red and Violet systems. They are both easily excited and are frequently encountered as impurities in many types of spectra.

RED SYSTEM

Occurrence. In the carbon arc in air, in the flame of burning cyanogen, in discharge tubes containing nitrogen and carbon compounds and especially strongly when vapours such as C₂H₂ and HCCl₃ are introduced into active nitrogen.

Appearance. Degraded to red. Triple-headed bands roughly equally spaced. See Plate 9.

Transition. ²Π → ²Σ, ground state.

References. A. Fowler and H. Shaw, *P.R.S.*, **86**, 118. (1911)†.

F. A. Jenkins, *P.R.*, **39**, 16. (1932).

R. K. Asundi and J. W. Ryde, *Nature*, **124**, 57. (1929).

The following table is compiled from the above references. The bands in the infra-red are by Asundi and Ryde; only the R₂ heads of these are given and no intensities are available. Most of the other bands are from Fowler and Shaw, with the wave-lengths reduced by 0.6 Å. to bring them into line with Jenkin's measurements. Intensities I_f, I_v, and I_n refer to cyanogen flame, vacuum tube, and active nitrogen. In all cases the R₂, R₁, and Q₁ heads are of about equal strength, the central R₁ head being perhaps a little the stronger. The ^sR₂₁ heads, where observed, are much weaker.

λ	I _f	I _v	I _n	v', v''		λ	I _f	I _v	I _n	v', v''	
9393	9*			1, 1	R ₂	6954.3	2	2	1	2, 0	Q ₁
9140.5	10*			0, 0	R ₂	6945.4					R ₁
8708				5, 4	R ₂	6927.6					R ₂
8485				4, 3	R ₂	6817.6	0	2	3	7, 4	Q ₁
8272				3, 2	R ₂	6809.2					R ₁
8067	8*			2, 1	R ₂	6792.5					R ₂
7874	10*			1, 0	R ₂	6779.6					^s R ₂
7435				5, 3	R ₂	6656.6	4	9	7	6, 3	Q ₁₁
7283				4, 2	Q ₁	6648.1					R ₁
7273					R ₁	6631.6					R ₂
7259					R ₂	6620.8					^s R ₂₁
7119				3, 1	Q ₁	6502.3	9	10	10	5, 2	Q ₁
7110					R ₁	6494.1					R ₁
7091					R ₂	6478.7					R ₂
6961.0		1	1	8, 5	R ₂	6466.7					^s R ₂₁

* As observed by Gaydon in CH₄-N₂O flame.

CN (contd.)

λ	I_f	I_s	I_n	v', v''		λ	I_f	I	I_n	v', v''	
6456.4		1	1	10, 6	Q ₁	5606.7					R ₂
6448.3					R ₁	5615.7	3	3	4	9, 4	Q ₁
6432.7					R ₂	5610.5					R ₁
6355.1	10	9	6	4, 1	Q ₁	5598.3					R ₂
6347.0					R ₁	5590.6					^s R ₂₁
6332.2					R ₂	5490.2	2	5	5	8, 3	Q ₁
6301.2		1	2	9, 5	Q ₁	5484.9					R ₁
6293.7					R ₁	5473.3					R ₂
6279.4					R ₂	5466.6					^s R ₂₁
6271.9					^s R ₂₁	5365.0	2	4	6	7, 2	Q ₁
6213.8	6	4	1	3, 0	Q ₁	5354.1					R ₁
6206.1					R ₁	5347.5					R ₂
6191.7					R ₂	5254.9	2	3	5	6, 1	Q ₁
6153.5	0	3	3	8, 4	Q ₁	5250.0					R ₁
6146.8					R ₁	5239.3					R ₂
6133.0					R ₂	5232.6					^s R ₂₁
6123.8					^s R ₂₁	5155.7			1	10, 4	R ₂
6012.5	2	6	6	7, 3	Q ₁	5129.7		1	1	5, 0	R ₂
6006.0					R ₁	5043.1		1	1	9, 3	R ₂
5992.6					R ₂	4949.1	1	2	3	8, 2	Q ₁
5984.3					^s R ₂₁	4945.3					R ₁
5877.6	2	9	9	6, 2	Q ₁	4835.8					R ₂
5871.3					R ₁	4930.7					^s R ₂₁
5858.2					R ₂	4845.3	1	?	4	7, 1	Q ₁
5849.3					^s R ₂₁	4841.7					R ₁
5748.7	5	7	7	5, 1	Q ₁	4832.6					R ₂
5742.7					R ₁	4827.7					^s R ₂₁
5730.2					R ₂	4784.9			1	11, 4	R ₂
5721.8					^s R ₂₁	4732.7			2	6, 0	R ₂
5728.5		1	1	10, 5	R ₂	4682.0			2	10, 3	R ₂
5625.0		2	2	4, 0	Q ₁	4488.8			0	8, 1	R ₂
5618.8					R ₁	4373.8			0	11, 3	R ₂

Note added in Proof.

G. Herzberg and J. G. Phillips (*Astrophys. J.*, 108, 163, (1948)) have recently shown that the v' values require raising by one unit, and have given the following additional measurements. Intensities are for a discharge through a mixture of argon, nitrogen and benzene.

λ	I	v', v''		λ	I	v', v''	
14074	4	0, 1	R ₂	9198.1	7	1, 0	Q ₁
				9174.7			R ₁
11247	1	1, 1	R ₂	9148.3			R ₂
11009	10	0, 0	Q ₁	7915.3	3	2, 0	Q ₁
10970			R ₁	7898.6			R ₁
10933			R ₂	7876.4			R ₂
10879			R ₂₁	7852.9			R ₂₁
9392.5	4	2, 1	R ₂				

CN (*contd.*)

VIOLET SYSTEM

Occurrence. In carbon arc in air, in discharge tubes containing nitrogen and carbon compounds, and when carbon compounds are introduced into active nitrogen. These bands occur very frequently as impurities in discharge tube sources, and in arcs between carbon poles.

Appearance. In arc sources three strong sequences with heads at λ 4216, 3883, and 3590 degraded to the violet. In active nitrogen the heads of the 4216 and 3590 sequences are less marked, and "tail" bands are observed; these are degraded to the red. See Plate 9.

Transition. ${}^2\Sigma \rightarrow {}^2\Sigma$, ground state.

References. Main system. W. Jevons, *P.R.S.*, **112**, 407. (1926)†.

Tail bands. F. A. Jenkins, *P.R.*, **31**, 539. (1928)†.

M. W. Feast, *Proc. Phys. Soc.*, **A62**, 121. (1949).

Main System. Intensities I_c and I_n are for carbon arc and active nitrogen respectively. The values of I_c are our own estimates from Jevons's plates. The values of I_n are from Jenkins, reduced to a scale of 10. Degraded to violet.

λ	I_c	I_n	v', v''	λ	I	I_n	v', v''
4606.1	1	0	0, 2	4158.1	5	4	4, 5
4578.0	2	0	1, 3	4152.4	4		5, 6
4553.1	2	0	2, 4	3883.4	10	10	0, 0
4531.9	2	0	3, 5	3871.4	9	4	1, 1
4514.8	2	1	4, 6	3861.9	8	4	2, 2
4502.2	2	1	5, 7	3854.7	6	5	3, 3
4216.0	9	2	0, 1	3850.9	4		4, 4
4197.2	8	4	1, 2	3590.4	8		1, 0
4181.0	7	4	2, 3	3585.9	7		2, 1
4167.8	6	3	3, 4	3583.9	6		3, 2

Tail Bands in Active Nitrogen. Wave-lengths λ_h and λ_o are for the heads and the origins of the bands respectively. Intensities are on a scale of 40 for the (0, 0) band at 3883. Degraded to the red.

λ_h	λ_o	I	v', v''	λ_h	λ_o	I	v', v''
4078.7	4083.2	1	15, 15	3658.1	3665.3	2	11, 10
4029.3	4034.6	3	14, 14	3628.9	3638.4	4	10, 9
3984.6	3991.1	5	13, 13	3603.0	3616.6	9	9, 8
3944.7	3953.3	8	12, 12	3501.4	3504.8	0	13, 11
3909.5	3920.8	9	11, 11		3469.1	0	12, 10
	3894.1	10	10, 10	3433.0	3437.8	0	11, 9
	3697.1	0	12, 11				

Tail Bands in Carbon Arc. The tail bands are also observed in the carbon arc in air. They are much weaker than the bands of the main system. The following measurements, intensities and vibrational assignments for the heads are by M. W. Feast. The intensities are on a scale of 10 for the (11, 11) band.

CN (*contd.*)

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
4028.4	6	14, 14	3465.3	6	12, 10	3296.3	3	5, 3
3984.5	9	13, 13	3432.9	6	11, 9	3203.5	4	10, 7
3944.5	9	12, 12	3404.8	7	10, 8	3180.2	4	9, 6
3909.9	10	11, 11	3380.3	6	9, 7	3159.9	4	8, 5
3657.7	5	11, 10	3359.1	4	8, 6	3142.6	4	7, 4
3628.5	7	10, 9	3340.6	4	7, 5	3127.6	3	6, 3
3602.6	7	9, 8	3322.3	4	6, 4	3114.3	2	5, 2

C₂N₂, Cyanogen

Two systems of absorption bands have been observed for cyanogen gas. The stronger lies below 2300 Å. and the weaker system which appears with absorption through 1½ metres of gas at atmospheric pressure is in the region 3100–2400 Å.

References. Sho-Chow Woo and R. M. Badger, *P.R.*, **39**, 932. (1932).

Soo-Choo Woo and Ta-Kong Liu, *J. Chem. Phys.*, **5**, 161. (1937).

Strong bands of main system as observed by Sho-Chow Woo and Badger; most of the bands are shaded to longer wave-lengths.

λ	<i>I</i>	λ	<i>I</i>	λ	<i>I</i>
2237.7	3	2164.5	4	2107.4	7
2226.4	5	2145.6	4	2093.1	10
2200.0	5	2137.7	4	2054.6	7
2188.2	9	2125.0	7	2035.2	7
				2007.0	10

Strongest bands of weak system as observed by Soo-Choo Woo and Ta-Kong Liu; narrow bands degraded to the red.

λ	<i>I</i>	λ	<i>I</i>	λ	<i>I</i>
3002.7	3	2759.2	3	2614.0	4
2831.1	3	2678.5	4	2540.3	5
2828.6	5	2675.6	6	2508	7

CO

Many band systems are known for CO. The electronic levels involved are singlet and triplet. Some of the systems are very frequently obtained as impurities in the spectra from discharge tubes. The bands most commonly encountered are the Angstrom bands in the visible, the Third Positive system in the near ultra-violet and the Fourth Positive system in the far ultra-violet and vacuum regions. A trace of CO in one of the rare gases often gives the Triplet system.

THE ANGSTROM SYSTEM

Occurrence. Readily obtained with CO or CO₂ in the positive column of an uncondensed discharge. The glass of a new discharge tube usually produces enough CO to give these bands and those of the Third Positive system.

Appearance. A progression of bands with strong single heads degraded to the violet. See Plate 2.

Transition. B ¹Σ → A ¹Π.

CO (contd.)

- References.* R. C. Johnson and R. K. Asundi, *P.R.S.*, **123**, 560. (1929).
 E. Hulthén, *Ann. Physik*, **71**, 41. (1923).
 O. Jasse, *C.R., Acad. Sci., Paris*, **182**, 692. (1926).

The following are the heads usually observed :—

λ	I	v', v''	λ	I	v', v''
6620.3	7	0, 5	5198.2	10	0, 2
6299	2	1, 6	5016	1	1, 3
6079.9	9	0, 4	4835.3	10	0, 1
5818	2	1, 5	4510.9	10	0, 0
5610.2	10	0, 3	4393.1	8	1, 1
5399	2	1, 4	4123.6	7	1, 0

THE HERZBERG SYSTEM

Occurrence. From CO in discharge tubes and controlled electron sources with conditions favourable for the production of the Angstrom bands.

Appearance. The bands are degraded to the violet and are very similar in appearance to the Angstrom bands.

Transition. $C\ ^1\Sigma \rightarrow A\ ^1\Pi$.

- References.* O. S. Duffendack and G. W. Fox, *Astrophys. J.*, **65**, 214. (1927).
 R. C. Johnson and R. K. Asundi, *P.R.S.*, **123**, 560. (1929).
 G. Herzberg, *Z.P.*, **52**, 815. (1929).

λ	I	v', v''	λ	I	v', v''
5705.9	1	0, 7	4380.3	7	0, 3
5318.4	1	0, 6	4124.8	7	0, 2
4972.8	2	0, 5	3893.1	7	0, 1
4661.3	5	0, 4	3680.9	4	0, 0

FOURTH POSITIVE SYSTEM

Occurrence. The system appears very readily in the positive column of discharge tubes containing carbon monoxide or carbon dioxide. It is emitted weakly by a carbon arc and an oxy-acetylene flame. The shorter wave-length end of the system can also be obtained in absorption.

Appearance. Degraded to the red. An extensive system of apparently single-headed bands extending from 2800 Å. to 1000 Å. See Plate 2.

Transition. $A\ ^1\Pi \rightarrow X\ ^1\Sigma$, ground state.

- References.* R. S. Estey, *P.R.*, **35**, 309. (1930).
 L. B. Headrick and G. W. Fox, *P.R.*, **35**, 1033. (1930)†.
 D. N. Read, *P.R.*, **46**, 571. (1934).

The following measurements of the bands of wave-length greater than 2000 Å. are by Estey; these values are about $\frac{1}{2}$ Å. smaller than the measurements by Read or Headrick and Fox, whose measurements are, however, chiefly concerned with the shorter wave-length end of the spectrum.

CO (contd.)

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
2799.7	9 ?	9, 22	2492.9	8	10, 20	2247.2	7	8, 16
2785.4	8 ?	4, 18	2483.8	3	6, 17	2238.3	9	4, 13
2742.6	6	11, 23	2463.2	10	9, 19	2221.5	10	7, 15
2740.0	4	7, 20	2458.0	2	5, 16	2215.8	3	3, 12
2712.1	4	6, 19	2433.9	9	8, 18	2196.8	10	6, 14
2698.3	6	13, 24	2424.1	5	11, 20	2173.0	9	5, 13
2684.0	3	5, 18	2407.6	7	7, 17	2150.2	8	4, 12
2680.8	5	9, 21	2394.2	3	10, 19	2137.0	5	7, 14
2662.9	4	12, 23	2393.1	4	13, 21	2128.3	8	3, 11
2661.5	4	15, 25	2381.6	6	6, 16	2113.1	9	6, 13
2659.6	4	4, 17	2365.5	5	9, 18	2107.2	7	2, 10
2630.0	6	11, 22	2356.5	4	5, 15	2089.9	10	5, 12
2598.3	4	10, 21	2337.9	7	8, 17	2086.9	1	1, 9
2594.5	1	16, 25	2332.5	3	4, 14	2067.6	10	4, 11
2567.8	5	9, 20	2311.5	8	7, 16	2046.3	10	3, 10
2556.0	3	12, 22	2286.1	7	6, 15	2025.8	9	2, 9
2538.6	4	8, 19	2273.9	3	9, 17	2011.8	8	5, 11
2521.8	3	14, 23	2272.3	1	12, 19	2005.8	5	1, 8
2509.9	8	7, 18	2261.7	9	5, 14			

THE THIRD POSITIVE AND 5B BANDS

These bands fall into two progressions which at one time were thought to belong to two different systems. Some papers therefore refer to one progression as the Third Positive Bands and the other as the 5B Bands; other papers refer to all the bands as the Third Positive System.

Occurrence. With CO in discharge tubes under a wide range of conditions. A mere trace of CO gives the bands strongly in the positive column with an uncondensed discharge.

Appearance. A progression of five strong bands with five close subheads forming the Third Positive group, consisting of the strongest members of the $(0, v'')$ progression, and a weaker progression of bands of a similar type forming the 5B group. Degraded to the violet. See Plate 2.

Transition. $b^3\Sigma \rightarrow a^3\Pi$.

References. G. H. Dieke and J. W. Mauchly, *P.R.*, 43, 12, (1933).

O. S. Duffendack and G. W. Fox, *Astrophys. J.*, 65, 214. (1927).

B. S. Beer, *Z.P.*, 107, 73. (1937).

λ	3rd Pos.		λ	5B.	
	I	v', v''		I	v', v''
2833.1	10	0, 0	2665.3	8	1, 0
2977.4	9	0, 1	2793.1	2	1, 1
3134.4	8	0, 2	2930	1	1, 2
3305.7	7	0, 3	3079.9	5	1, 3
3493.3	6	0, 4	3242.1	6	1, 4
3699	2	0, 5	3419.2	5	1, 5
			3612.7	5	1, 6
			3825.1	2	1, 7

CO (contd.)

THE ASUNDI BANDS

Occurrence. In the positive column of a discharge tube containing CO.

Appearance. Bands degraded to the red with complex structure; probably containing five heads.

Transition. $a' \ ^3\Sigma \rightarrow a \ ^3\Pi$.

References. R. K. Asundi, *P.R.S.*, **124**, 277. (1929).

L. Gerö and K. Lorinczi, *Z.P.*, **113**, 449. (1939).

The following measurements are by Asundi who used small dispersion and measured only two extreme heads for each band.

λ	I	v', v''	λ	I	v', v''
8592	2	1, 0	6804.0	8	7, 2
8222.5	1	3, 1	6685.7	7	4, 0
7833.9	3	2, 0	6513.5	9	6, 1
7552.5	1	4, 1	6366.9	5	8, 2
7314.0	2	6, 2	6244.0	5	5, 0
7210.4	5	3, 0	6105.2	5	7, 1
7116.5	3	8, 3	5861.0	6	6, 0
6990.2	2	5, 1	5749.1	6	8, 1

According to Gerö and Lorinczi the values of v' given by Asundi should be increased by three units.

THE TRIPLET BANDS

Occurrence. Obtained by Merton and Johnson in a wide-bore discharge tube containing helium and hydrogen with a trace of CO with an uncondensed discharge.

Appearance. With moderate dispersion the bands, which are degraded to the red, show a well-marked triplet structure.

Transition. $d \ ^3\Pi \rightarrow a \ ^3\Pi$.

References. T. R. Merton and R. C. Johnson, *P.R.S.*, **103**, 383. (1923)†.

L. Gerö and F. Szabó, *Ann. Physik.*, **35**, 597. (1939).

R. Herman and L. Herman, *J. Phys. Radium*, **9**, 160. (1948)†.

The following are the wave-lengths and vibrational assignments given by Herman and Herman with intensities given by Merton and Johnson:—

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
6464.6			*5836.9			*5428.3		
6433.1	10	0, 0	5812.1	2		5414.5	1	
6401.0			5779			5402.5		
*6383.1			5670.5			5351.2		
6348.7	1		5647.6	6	2, 0	5330.5	5	3, 0
6319.8			5624			5308		
6037.0			5554.1			5258.3		
6010.5	8	1, 0	5532.5	5	4, 1	5238.4	5	5, 1
5982			5508			5216		

* These bands recorded by Merton and Johnson are not included in the system by Herman and Herman, who consider another system to be present. The bands of this new system also have three heads and possibly the same initial level as the Triplet Bands.

CO (contd.)

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
*5140.3			4602.6			4343.8		
5128.1	2		4586.4	7	6, 0	4328.7		11, 2
5116.2			4571			4314.1		
5070.9			4556.5			4326		
5052.7	8	4, 0	4541.0	5	8, 1	4312		13, 3
5033			4524.0			4297		
4996.9			4520.7			4227.2		
4979.0	6	6, 1	4505.5		10, 2	4213.7		8, 0
4959.0			4488.4			4198.9		
4935.5			4494.4			4201.5		
4917.2	2	8, 2	4478.8		12, 3	4188.4		10, 1
4897.5			4462.9			4174.6		
4880.8			4466			4182.5		
4869.3		10, 3	4452.2		16, 5	4171		12, 2
—			—			4157		
4823.5			—			—		
4806.7	8	5, 0	4460.4		14, 4	4036.4		
4787			4444.7			4023.7		13, 2
						4011		
4764.8			4405.0					
4747.5	5	7, 1	4390.9		7, 0			
—			4374.0					
4680.3			4369.9					
—		11, 3	—		9, 1			
4646.7			4339.4					

* These bands recorded by Merton and Johnson are not included in the system by Herman and Herman, who consider another system to be present. The bands of this new system also have three heads and possibly the same initial level as the Triplet Bands.

THE CAMERON BANDS

Occurrence. Cameron obtained these bands in a wide-bore discharge tube filled with neon using an uncondensed discharge but with low intensity. Hansche using a continuous-wave oscillator to excite CO in a 12-litre flask finds that the Cameron bands reach a maximum intensity at a pressure between 0.003–0.002 mm. of Hg. May also be obtained in absorption.

Appearance. Degraded to the red. Five close heads to each band.

Transition. $a^3\Pi \rightarrow X^1\Sigma$. Intercombination to ground state.

References. W. H. B. Cameron, *Phil. Mag.*, **1**, 405. (1926).

G. Herzberg, *Z.P.*, **52**, 815. (1929).

L. Gerö, G. Herzberg and R. Schmid, *P.R.*, **52**, 467. (1937).

G. E. Hansche, *P.R.*, **57**, 289. (1940).

CO (contd.)

The following are Cameron's wave-lengths for the furthest ultra-violet head of each band. The data for the (0, 0) and (1, 0) bands are added from the paper by Gerö, Herzberg and Schmid.

λ	I	v', v''	λ	I	v', v''
2575.3	8	4, 8	2409.2	7	2, 5
2553.3	6	3, 7	2388.8	7	1, 4
2531.9	4	2, 6	2369.0	3	0, 3
2510.9	6	1, 5	2277.0	1	1, 3
2492.9*	4	0, 4	2257.7	1	0, 2
2451.8	6	4, 7	2059.6		0, 0
2430.3	3	3, 6	1989.4		1, 0

* Second head; first missing.

THE 3A BANDS

Occurrence. In discharge tube containing CO. Schmid and Gerö obtained them with high intensity in a discharge tube containing neon with carbon electrodes.

Appearance. Degraded to the violet with five heads close together. Under low dispersion appear double-headed.

Transition. $c\ ^3\Sigma \rightarrow a\ ^3\Pi$.

References. R. Schmid and L. Gerö, *Nature, Lond.*, **139**, 928. (1937).

R. K. Asundi, *P.R.S.*, **124**, 277. (1929).

L. Gerö, *Z.P.*, **109**, 210. (1938).

λ	I	v', v''
2711.3	3	0, 4
2596.9	4	0, 3
2489.9	5	0, 2
2389.7	5	0, 1
2295.9	4	0, 0

OTHER BANDS OF CO

Knauss Bands. Four bands were obtained in an electrodeless discharge through CO. The bands were degraded to the violet and assigned to the transition $C\ ^1\Sigma \rightarrow a\ ^3\Sigma$.

Reference. H. P. Knauss and J. C. Cotton, *P.R.*, **36**, 1099. (1930).

The approximate wave-lengths are :—

λ	v', v''
3253	0, 3
3138	0, 2
3028	0, 1
2925	0, 0

Kaplan Bands. (1) Three bands were obtained in a long atomic hydrogen tube. Each band apparently contained six heads degraded to the violet and resembled

CO (contd.)

the bands of the Third Positive and 3A systems. Wave-lengths given by Kaplan were 2750 Å., 2630 Å., 2518 Å.

Reference. J. Kaplan, *P.R.*, **35**, 1298. (1930).

(2) An intense band at 2575 Å., degraded to the red, was obtained in quenching mercury-resonance radiation by CO. This coincides in position with the (0, 0) band of CS.

Reference. J. Kaplan, *P.R.*, **36**, 788. (1930).

CO⁺

There are three band systems attributed to ionised carbon monoxide, the First Negative Carbon bands, the Comet-tail bands, and the Baldet-Johnson system.

FIRST NEGATIVE SYSTEM

Occurrence. In the cathode glow of discharge tubes containing CO or CO₂, especially in hollow cathode. Also in discharges through helium containing a trace of CO. These bands, like most systems of CO, are very frequent impurities in discharge tubes, especially at low pressures. They also occur in an electron beam.

Appearance. Degraded to red. Single-headed bands forming fairly obvious sequences. See Plate 2.

Transition. B ²Σ → ²Σ, ground state.

References. R. C. Johnson, *P.R.S.*, **108**, 343. (1925)†.

H. Biskamp, *Z.P.*, **86**, 33. (1933).

The following values are from Biskamp's measurements. A few weak bands below 2000 Å. are omitted.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
3152.7	1	8, 13	2607.2	8	2, 5	2220.3	0	8, 6
3107.5	2	7, 12	2577.7	10	1, 4	2214.5	5	1, 1
3064.0	3	6, 11	2550.3	7	0, 3	2189.8	10	0, 0
3023.0	2	5, 10	2530.8	1	4, 6	2185.1	4	7, 5
2984.2	2	4, 9 8, 12	2504.6	10	3, 5	2164.3	5	3, 2
2947.6	1	3, 8	2474.2	10	2, 4	2154.1	4	6, 4
2938.5	1	7, 11	2445.8	10	1, 3	2137.8	6	2, 1
2913.2	1	2, 7	2419.4	8	0, 2	2123.8	3	5, 3
2897.2	3	6, 10	2412.4	4	4, 5	2112.4	8	1, 0
2882.2	2	1, 6	2381.5	5	3, 4	2095.3	5	4, 2
2874.5	0	9, 12	2362.5	1	6, 6	2091.0	4	7, 4
2858.1	4	5, 9	2352.5	6	2, 3	2067.9	1	3, 1
2820.8	5	4, 8	2325.2	9	1, 2	2067.8	1	9, 5
2785.8	5	3, 7	2299.6	10	0, 1	2061.0	3	6, 3
2752.9	6	2, 6	2298.2	3	4, 4	2042.3	4	2, 0
2745.1	1	6, 9	2293.7	1	10, 8	2034.3	2	8, 4
2722.3	7	1, 5	2268.6	3	3, 3	2032.3	1	5, 2
2707.9	3	5, 8	2255.7	1	9, 7	2004.7	0	4, 1
2693.9	2	0, 4	2254.3	2	6, 5	2003.1	0	7, 3
2672.4	7	4, 7	2240.4	4	2, 2			
2638.8	8	3, 6	2222.7	4	5, 4			

CO⁺ (contd.)

COMET-TAIL SYSTEM

Occurrence. In discharge tubes containing CO or CO₂ at relatively very low pressure, in electron beam through CO at low pressure, in discharge tubes containing helium with a trace of CO, and in the tails of comets.

Appearance. Degraded to red. Double-headed bands. See Plate 8.

Transition. A ²Π → ²Σ, ground state.

References. M. F. Baldet, *C.R. Acad. Sci. Paris*, **180**, 271. (1925).

M. F. Baldet, *C.R. Acad. Sci. Paris*, **180**, 820. (1925).

T. R. Merton and R. C. Johnson, *P.R.S.*, **103**, 383. (1923)†.

R. C. Johnson, *P.R.S.*, **108**, 343. (1925).

D. Coster, H. H. Brons and H. Bulthuis, *Z.P.*, **79**, 787. (1932).

The measurements and intensities as listed below are average values compiled from the above references; the list given by Baldet is the most complete. Except for the two strongest bands only the two R heads are given here. The corresponding Q heads lie from 5 (for bands in the red) to 1.5 Å. to the red of the R heads. The Q heads are rather stronger than the R heads, but are usually masked by the overlapping lines of the R branch. The R₂ head is always a little stronger than the R₁ head. The values of *v'* given previously have been reduced by 3 to make them consistent with the analysis of the Baldet-Johnson system.

λ	I	v', v"	λ	I	v', v"	λ	I	v', v"
6405	0	R ₂	4865.8	1	3, 2 R ₂	4019.7	9	3, 0 Q ₂
6354		R ₁	4836.6		R ₁	4017.7		R ₂
						3999.6		Q ₁
6238.7	7	0, 2 R ₂	4711.2	5	2, 1 R ₂	3997.3		R ₁
6189.4		R ₁	4683.4		R ₁			
						3908.0	2	5, 1 R ₂
6015	0	R ₂	4565.8	8	1, 0 R ₂	3888.6		R ₁
5970		R ₁	4539.4		R ₁			
						3795.8	8	4, 0 R ₂
5900.4	1	2, 3 R ₂	4518.0	3	4, 2 R ₁	3777.8		R ₁
5856.5		R ₁						
			4403.3	2	3, 1 R ₂	3705.3	4	6, 1 R ₂
5806	0	R ₂	4378.9		R ₁	3688.1		R ₁
5764		R ₁						
			4274.3	10	2, 0 Q ₂			
5693.6	3	1, 2 R ₂	4272.0		R ₂	3600.8	6	5, 0 R ₂
5652.6		R ₁	4252.4		Q ₁	3584.2		R ₁
			4248.9		R ₁			
5499.9	6	0, 1 R ₂				3525.6	2	7, 1 R ₂
5461.4		R ₁	4244.1	1	5, 2 R ₁	3510.3		R ₁
5072.1	5	1, 1 R ₂	4151.9	1	7, 3 R ₂	3427.9	4	6, 0 R ₂
5039.7		R ₁	4130.4		R ₁	3413.3		R ₁
4910.9	3	0, 0 R ₂	4138.9	2	4, 1 R ₂	3366.1	2	8, 1 R ₂
4879.5		R ₁	4117.3		R ₁	3351.7		R ₁

CO⁺ (contd.)

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
3314.2	1	10, 2 R ₂	3222.4	1	9, 1 R ₂	3135.5	1	8, 0 R ₂
3300.7		R ₁	3209.7		R ₁	3123.2		R ₁
3273.9	2	7, 0 R ₂	3180.3	1	11, 2 R ₂	3093.3	0	10, 1 R ₂
3260.4		R ₁	3168.1		R ₁	3081.5		R ₁

BALDET-JOHNSON SYSTEM

Occurrence. In discharge through helium containing a trace of CO, and in electron beam through CO at low pressure. This is an intercombination system between the initial levels of the First Negative and the Comet-tail systems and occurs under similar conditions.

Appearance. Degraded to shorter wave-lengths. Double double-headed bands.

Transition. B ² Σ \rightarrow A ² Π , initial state of Comet-tail bands.

References. R. C. Johnson, *P.R.S.*, **108**, 343. (1925)†.

M. F. Baldet, *C.R. Acad. Sci. Paris*, **178**, 1525. (1924).

The measurements and intensities listed below are averaged values from the above references :—

λ	I	v', v''	λ	I	v', v''
4236.2	3	0, 1 P ₁	3729.7	3	1, 0 P ₁
4231.6	8	Q ₁	3724.9	8	Q ₁
4212.9	7	P ₂	3711.2	9	P ₂
4209.1	8	Q ₂	3707.4	9	Q ₂
—			3515.8	2	2, 0 P ₁
4201.5	1	1, 2 Q ₁	3511.7	7	Q ₁
4182.6	1	P ₂	3500.4	3	P ₂
4179.1	1	Q ₂	3496.7	4	Q ₂
3977.7	4	0, 0 P ₁	3331.9	1	3, 0 P ₁
3973.5	9	Q ₁	3329.0	1	Q ₁
3957.0	7	P ₂	3317.9	1	P ₂
3953.6	10	Q ₂	3314.8	1	Q ₂

CO₂ and CO₂⁺

Two extensive band systems are believed to be due to the neutral CO₂ molecule ; the first has been studied extensively by Fox, Duffendack and Barker, and the second occurs in the flame of burning carbon monoxide. Two very strong persistent bands at about 2883 and 2896 A. are probably due to the ionised molecule CO₂⁺.

FOX, DUFFENDACK AND BARKER'S SYSTEM

Occurrence. In the negative glow of discharges through streaming carbon dioxide ; the bands appear strongly in a hollow cathode and have also been produced with a trace of carbon dioxide in the presence of helium or neon. The bands have been observed as an impurity in the spectrum of what was thought to be pure oxygen. The spectrum has been studied most completely when excited by a beam of electrons

CO₂ and CO₂⁺ (contd).

through streaming carbon dioxide at low pressure; as observed in this way the bands are fairly free from the many systems due to CO.

Appearance. Narrow bands degraded to the red. The system extends from 2800 to nearly 5000 Å. At the ultra-violet end the appearance is relatively simple, the bands forming marked groups which resemble sequences, but the longer wavelength end is very confused and presents few definite features. See Plate 2.

References. H. D. Smyth, *P.R.*, **38**, 2000. (1931)†.

S. Mrozowski, *P.R.*, **60**, 730. (1941).

There are several earlier papers by Fox, Duffendack and Barker and colleagues, and R. Schmid has more recently made good progress with the rotational analysis.

The following measurements are by Fox, Duffendack and Barker (after Smyth) and the intensities are by Smyth for electron beam excitation. Only the strong bands are reproduced here. Bands marked with an asterisk are at the head of characteristic groups which are prominent in the spectrum as obtained from discharge tubes.

λ	I	λ	I	λ	I	λ	I
4159.5	5	3761.4	4	3400.9	5	3155.2	5
4137.6	6	3691.8	6	3394.5	4	3149.5	4
4120.8	6	3674.1	5	3388.9	4	3139.2	5
4107.9	5	*3661.6	5	3377.5	8	3136.7	5
4070.7	5	3621.0	7	*3370.0	8	3134.6	4
4048.9	5	3565.5	5	3284.3	3	*3132.9	4
3960.9	7	3562.2	6	3269.9	5	3063.5	4
3890.4	4	3551.4	6	3264.6	5	3058.3	4
3870.5	7	3545.9	7	3253.9	6	3048.6	5
3853.2	4	3533.8	4	*3246.9	6	3034.2	4
3838.8	6	3510.8	3	3164.9	3	2874.3	5
3774.6	4	*3503.2	3				

CARBON MONOXIDE FLAME SPECTRUM

Occurrence. In flame of carbon monoxide burning in air or oxygen. The bands have also been observed in the afterglow of a heavy current discharge through carbon dioxide.

Appearance. A great number of narrow bands, not clearly degraded in either direction, on a continuous background. The bands are strongest between 5000 Å. and 3500 Å., with maximum intensity around 4200 Å., but the system can be extended from the green to beyond the OH band at 3064 Å. with long exposure. The bands are favoured, relatively to the continuous background, by low pressure. See Plate 9.

References. F. R. Weston, *P.R.S.*, **109**, 176. (1925)†.

A. Fowler and A. G. Gaydon, *P.R.S.*, **142**, 362. (1933)†.

A. G. Gaydon, *P.R.S.*, **176**, 505. (1940)†.

This complex system is best identified by direct comparison of photographs, but the following measurements (from Weston) of the maxima of the strongest bands may be of assistance. λ 5430, 5318, 5278, 5169, 5129, 5026, 4981, 4932, 4896, 4798, 4769, 4659, 4654, 4577, 4557, 4528, 4485, 4413, 4344, 4260, 4154, 3911.

CO₂ and CO₂⁺ (contd.)**BANDS $\lambda\lambda 2883$ AND 2896**

Occurrence. These bands are very persistent and occur in almost all discharge tubes containing carbon dioxide or even carbon monoxide. They are favoured by freshly streaming gas and relatively energetic excitation, *i.e.*, negative glow or hollow cathode. They are of frequent occurrence as an impurity.

Appearance. Two strong narrow bands of almost line-like sharpness, each being a close doublet; intensity maxima at about $\lambda\lambda 2897.5$, 2895.1 , 2884.0 and 2881.8 . There are also weaker heads at $\lambda\lambda 2890.5$, 2877.5 and 2874.8 . See Plate 2.

References. R. Schmid, *Z.P.*, **83**, 711. (1933)†.
F. Bueso-Sanllehi, *P.R.*, **60**, 556. (1941)†.

C₃O₂

Occurrence. In absorption by carbon suboxide vapour.

Appearance. Narrow diffuse bands, evenly spaced in the region 3380–3250 Å. and occurring in pairs on a complex banded background in the region 3250–2910 Å.

Reference. H. W. Thompson and N. Healey, *P.R.S.*, **157**, 331. (1936).

The following are the maxima of the strong bands, $\lambda\lambda 3350$, 3332 , 3316 , 3302 , 3292 , 3277 , 3251 , 3175 , 3166 , 3136 , 3127 , 3092 , 3082 , 3047 , 3038 , 3015 , 3006 , 2994 , 2987 , 2955 and 2946 .

COS ?**EMISSION**

Occurrence. Discharge through flowing carbonyl sulphide vapour.

Appearance. Degraded to shorter wave-lengths. A regularly spaced group of bands.

Reference. A. Fowler and W. M. Vaidya, *P.R.S.*, **132**, 310. (1931).

Bands $\lambda\lambda 3077$, 3043 , 3009 , 2976 ?, 2943 , 2911 and 2880 .

ABSORPTION

Reference. W. Lochte-Holtgreven and C. E. H. Bawn, *Trans. Faraday Soc.*, **28**, 698. (1932).

Absorption band extending from a sharp edge at 2550 ± 20 Å. towards shorter wave-lengths.

CP

Two systems, with the same initial level, are known.

Occurrence. In discharge tubes containing argon, phosphorus and an organic vapour.

Reference. H. Barwald, G. Herzberg and L. Herzberg, *Ann. Physik*, **20**, 569. (1934)†.

SYSTEM A, NEAR ULTRA-VIOLET

Appearance. Degraded to red. Single-headed bands.

Transition. $B \ ^2\Sigma \rightarrow X \ ^2\Sigma$, probably ground state.

The following are the strong bands. Intensities have been increased to a scale of 10.

INDIVIDUAL BAND SYSTEMS

101

CP (contd.)

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
4014.8	8	1, 4	3459.2	10	0, 0	3190.2	8	3, 0
3957.1	6	0, 3	3363.5	10	1, 0	3111.8	6	4, 0
3777.9	8	0, 2	3320.1	6	3, 1	3038.6	5	5, 0
3612.4	10	0, 1	3273.7	6	2, 0	3054.8	6	8, 2
3508.2	8	1, 1	3235.3	6	4, 1	2969.1	6	6, 0

SYSTEM B, BLUE

Appearance. Degraded to the red. Double double-headed bands.

Transition. $B \ ^2\Sigma \rightarrow A \ ^2\Pi$.

The following are the strong heads. Intensities have been raised to a scale of 10 for the strongest band of System A.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
4653.0	4	2, 2 Q ₂	4551.3	4	0, 0 R ₂	4454.7	6	3, 2 Q ₁
4619.1	4	2, 2 Q ₁	4524.6	8	0, 0 Q ₁	4438.7	4	2, 1 R ₂
4605.3	4	1, 1 Q ₂	4517.5	3	0, 0 R ₁	4434.2	4	2, 1 Q ₂
4572.0	4	1, 1 Q ₁	4502.2	4	4, 3 Q ₁	4407.7	4	2, 1 Q ₁
4557.3	8	0, 0 Q ₂	4486.3	5	3, 2 Q ₂	4392.8	3	1, 0 Q ₂

CS

Occurrence. In vacuum tube discharge through carbon disulphide and in carbon arc fed with sulphur; also in low temperature phosphorescent flame of CS₂. The bands are frequently encountered as an impurity in discharge tube spectra.

Appearance. Degraded to the red. Close double-headed bands. The sequences are fairly obvious; the head of the (0, 0) band at 2576 A. is often very outstanding. See Plate 9.

Transition. Probably $^1\Pi \rightarrow ^1\Sigma$, ground state.

References. L. C. Martin, *P.R.S.*, **89**, 127. (1913)†.

W. Jevons, *P.R.S.*, **117**, 351. (1928).

F. H. Crawford and W. A. Shurcliff, *P.R.*, **45**, 860. (1934).

The following are the R heads of all the prominent bands as measured by Jevons. The Q heads lie from 0.5 to 2 A. to the red of the R heads. Intensities given below are for a discharge through CS₂.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
2852.3	2	0, 3	2677.0	6	1, 2	2523.2	7	2, 1
2836.8	2	5, 7	2662.6	10	0, 1	2511.2	3	6, 4
2819.5	3	4, 6	2638.9	2	4, 4	2507.3	4	1, 0
2801.5	5	3, 5	2621.6	7	3, 3	2493.7	6	5, 3
2785.7	5	2, 4	2605.9	10	2, 2	2477.0	4	4, 2
2769.2	3	1, 3	2589.6	6	1, 1	2473.4	3	8, 5
2754.7	7	0, 2	2575.6	10	0, 0	2460.2	5	3, 1
2743.9	3	5, 6	2572.7	5	5, 4	2454.3	1	7, 4
2726.7	4	4, 5	2555.8	5	4, 3	2444.8	3	2, 0
2708.9	7	3, 4	2538.7	8	3, 2	2436.0	1	6, 3
2693.2	8	2, 3	2530.0	3	7, 5	2418.4	0	5, 2

CS₂

Occurrence. Absorption by carbon disulphide vapour.

Appearance. A very complex system of headless bands.

References. E. D. Wilson, *Astrophys. J.*, **69**, 34. (1929).

L. N. Liebermann, *P.R.*, **60**, 496. (1941).

The following are the strongest maxima, with intensities reduced to a scale of 10 from Wilson's measurements.

λ	I	λ	I	λ	I	λ	I
3346.0	1	3227.4	3	3154.0	5	3080.7	4
3321.6	2	3214.3	7	3150.9	6	3056.8	2
3301.3	2	3204.4	9	3144.0	8	3036	2
3274.8	8	3189.5	10	3126.6	6	3023	2
3260.4	2	3181.5	6	3119.3	6	3009.4	1
3250.6	5	3170.2	6	3100.4	4	2993.4	1
3235	8	3161.9	5	3092.5	5		

CSe

Occurrence. High-frequency discharge through selenium vapour in a quartz tube on which carbon has been deposited.

Appearance. Degraded to the red. Some of the bands show double heads (separation about 5 Å.).

Transition. Probably ${}^1\Pi \rightarrow {}^1\Sigma$.

Reference. B. Rosen and M. Désirant, *C.R. Acad. Sci. Paris*, **200**, 1659. (1935).

The following are the stronger (presumably the R) heads of the bands observed:—

λ	v', v''	λ	v', v''	λ	v', v''
3053.3	2, 4	2963.9	2, 3	2861.6	1, 1
3038.3	1, 3	2948.0	1, 2	*2844.5	0, 0
3021.1	0, 2	2931.0	0, 1	2779.1	1, 0

* The (0, 0) band is stated to be the strongest; the weaker Q head is at 2848.9 Å.

CaBr

There are two systems, one in the red and the other in the violet, attributed to CaBr. In addition, a few weak bands have been observed in the ultra-violet.

RED SYSTEM

Occurrence. In absorption and when calcium bromide is introduced into a flame; the bands do not appear readily in an arc.

Appearance. Marked close sequences degraded to shorter wave-lengths.

Transition. Perhaps ${}^2\Pi \rightarrow {}^2\Sigma$, ground state.

References. K. Hedfeld, *Z.P.*, **68**, 610. (1931).

O. H. Walters and S. Barratt, *P.R.S.*, **118**, 120. (1928).

The following measurements and analysis are by Hedfeld. The intensities I_a and I_f are for absorption and for emission in a flame respectively, the former being by Walters and Barratt, who also report a band (intensity 5) at 6106.6.

INDIVIDUAL BAND SYSTEMS

103

CaBr (contd.)

λ	I_a	I_f	Sequence	λ	I_a	I_f	Sequence
6399.0		0	0, 1 P ₁	6258.8	0	5	0, 0 P ₂
6390.5	0	0	0, 1 Q ₁	6252.9	10	10	0, 0 Q ₂
6370.9		0	0, 1 P ₂	6176.8		0	1, 0 P ₁
6364.8	0	0	0, 1 Q ₂	6168.8	0	0	1, 0 Q ₁
6286.0	0	4	0, 0 P ₁	6150.6		0	1, 0 P ₂
6277.7	10	10	0, 0 Q ₁	6145.0	0	0	1, 0 Q ₂

VIOLET SYSTEM

Occurrence. In absorption and in flame.

Appearance. Degraded to longer wave-lengths. Close sequences.

References. C. M. Olmsted, *Z. wiss. Photogr.*, 4, 255. (1906).

O. H. Walters and S. Barratt, *P.R.S.*, 118, 120. (1928).

The following measurements of the strong bands are compiled from the above. Intensities I_a and I_f for absorption and flame.

λ	I_a	I_f	λ	I_a	I_f
3996	0	5	3917	4	6
3960	0	4	3910	0	3
3951	4	6	3878		4

ULTRA-VIOLET BANDS

Weak bands (intensity 0), degraded to shorter wave-lengths, reported by Walters and Barratt at $\lambda\lambda$ 2967, 2952, 2945, 2910 and 2890, in absorption.

CaCl

Occurrence. When CaCl₂ is introduced into an arc or flame.

Also in absorption, frequently as an impurity.

References. K. Hedfeld, *Z.P.*, 68, 610. (1931).

A. E. Parker, *P.R.*, 47, 349. (1935).

There are three strong systems, in the red, orange, and ultra-violet respectively. A few weak fragmentary systems are also reported by Parker.

RED SYSTEM, $\lambda\lambda$ 6361-6047

Appearance. Degraded to violet. Marked close sequences.

Transition. Perhaps A ²I_I → ²Σ, ground state.

Strongest heads :—

λ	I	v', v''	
6353.5	2	0, 1	Q ₁
6325.8	2		Q ₁
6224.9	5	0, 0	P ₁
6211.6	10		Q ₁
6193.4	5		P ₂
6184.9	10		Q ₂
6076.6	2	1, 0	Q ₁
6051.6	2		Q ₂

CaCl (*contd.*)ORANGE SYSTEM, $\lambda\lambda 6067-5810$

Appearance. Degraded to red. Close sequences.

Transition. Perhaps $B \ ^2\Sigma \rightarrow \ ^2\Sigma$, ground state.

$\lambda 5934.0$ head of (0, 0) sequence, intensity 10.

$\lambda 5809.9$,, ,, (1, 0) ,, ,, 4.

ULTRA-VIOLET SYSTEM, $\lambda\lambda 4023-3644$

Appearance. Degraded to red. Close sequences.

Transition. Perhaps $C \ ^2\Pi \rightarrow \ ^2\Sigma$, ground state.

No intensities given. Heads of sequences :—

λ	Sequence
3828.1	0, 1 Q_1
3816.9	Q_2
3775.0	0, 0 Q_1
3774.4	R_1
3764.2	Q_2
3763.5	R_2
3728.0	1, 0 Q_1
3727.4	R_1
3717.3	Q_2

CaF

Occurrence. When calcium fluoride is put in carbon arc or a flame. These bands often occur as impurities in arc spectra and have been recommended for use in analytical work as a test for the presence of fluorine. Also in absorption.

References. S. Datta, *P.R.S.*, **99**, 436. (1921)†.

R. C. Johnson, *P.R.S.*, **122**, 161. (1929).

A. Harvey, *P.R.S.*, **133**, 336. (1931)†.

C. A. Fowler, *P.R.*, **59**, 645. (1941)†.

There are three systems in emission, usually known as the orange, green and ultra-violet systems. The two former appear strongly, but the ultra-violet bands are weak and usually masked by CaO bands. C. A. Fowler has obtained three additional systems in absorption in the ultra-violet.

ORANGE SYSTEM

Transition. $A \ ^2\Pi \rightarrow \ ^2\Sigma$, ground state.

There are long sequences of heads of about equal intensity. The (0, 1) and (0, 0) sequences are degraded to the violet, the separation between successive heads being about 4.5 A. for the (0, 1) sequence and 2 A. for the (0, 0). The (1, 0) sequence is piled up on itself and shows a head at 5830 A., degraded to the red. See Plate 1.

The heads of the sequence only are listed :—

λ	I	Sequence
6285.3	4	(0, 1) Q_{12}
6256.6	4	(0, 1) Q_2
6086.9	5	(0, 0) P_{12}

CaF (*contd.*)

λ	I	Sequence
6064.4	10	(0, 0) Q_{12}
6050.8	6	(0, 0) P_2
6036.9	6	(0, 0) Q_2
5830	5	(1, 0) Degraded to red

GREEN SYSTEM

Transition. B $^2\Sigma \rightarrow ^2\Sigma$, ground state.

Strong (0, 0) sequence of double-headed bands degraded to the red. The heads are separated by about 1.8 A., and successive bands of the sequence by about 6 A. There is a weaker (1, 0) sequence of similar appearance. See Plate 1.

λ	v', v''	
5291.0	(0, 0)	R_2
5292.9	(0, 0)	R_1
5296.8	(1, 1)	R_2
5298.6	(1, 1)	R_1
	etc.	
5145.4	(1, 0)	R_2
5146.4	(1, 0)	R_1
5151.9	(2, 1)	R_2
5152.8	(2, 1)	R_1
	etc.	

ULTRA-VIOLET SYSTEMS

Transition. C $^2\Pi \rightarrow ^2\Sigma$, ground state.

Two sequences degraded to the red appear in emission. The first few heads of each sequence as measured by Datta are given :—

λ	λ
3371.1	3449.2
3373.2	3459.9
3382.6	3462.0
3384.6	3470.6
3393.7	3472.8
3395.9	3481.2
etc.	etc.

Fowler gives a formula for the Q_1 heads obtained in absorption which yields the wave-lengths given below. The R_1 heads are about 1 A. and the R_2 heads about 3 A. to the short wave-length side of the Q_1 heads.

Q_1 heads :—

λ	I	v', v''
3375.1	7	0, 1
3386.5	6	1, 2
3310.0	10	0, 0
3258.5	5	1, 0
3270.1	5	2, 1

Transition. D $^2\Sigma \leftarrow X^2\Sigma$, ground state.

Appearance. Degraded to the violet. Fowler obtained absorption over the range

CaF (*contd.*)

$\lambda\lambda 3245-3081$. The following wave-lengths have been calculated from Fowler's formula for the heads. The intensities where given are those observed by Fowler.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
3372.2		0, 2	3238.8	8	1, 1	3167.3	9	3, 2
3307.9		0, 1	3232.2	6	2, 2	3115.6	1	2, 0
3300.4		1, 2	3178.9	6	1, 0	3110.5	5	3, 1
3245.4	10	0, 0	3173.1	8	2, 1	3055.2		3, 0

Transition. $E \ ^2\Sigma \leftarrow X \ ^2\Sigma$, ground state.

Appearance. Degraded to the violet. Fowler obtained absorption over the range $\lambda\lambda 3035-2754$. Wave-lengths calculated from Fowler's formula for the heads with his observed intensities:—

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
3028.8		0, 2	2921.2	4	1, 1	2821.1	4	2, 0
2976.9	4	0, 1	2872.4	8	1, 0	2717.5	6	3, 1
2926.2	10	0, 0	2868.2	7	2, 1	2814.0	7	4, 2

Transition. $F \ ^2\Pi \leftarrow X \ ^2\Sigma$, ground state.

Appearance. Degraded to the violet, region $\lambda\lambda 2700-2554$.

P_1 heads obtained from Fowler's formula:—

2700.9 (6) (0, 1), 2659.1 (10) (0, 0), 2612.2 (6) (1, 0), 2567.5 (1) (2, 0).

The P_2 heads are 0.1 A. and the Q_2 heads 1.0 A. to the violet of the P_1 heads.

CaH

Five systems have been observed and analysed, of which the strongest are systems A and B.

References. E. Hulthén, *P.R.*, **29**, 97. (1927).

B. Grundström and E. Hulthén, *Nature, Lond.*, **125**, 634. (1930).

B. Grundström, *Z.P.*, **69**, 235 (1931)†.

Z.P., **75**, 302 (1932).

Z.P., **95**, 574 (1935).

W. W. Watson and R. L. Weber, *P.R.*, **48**, 732. (1935).

6946 A. A-SYSTEM, $A \ ^2\Pi \rightarrow ^2\Sigma$, ground state.

Bands degraded to the violet. Obtained in calcium arcs in hydrogen at various pressures. Observed in absorption by mixture of hydrogen and calcium vapour. Identified in the sun-spot spectrum.

v', v''	Origins	Heads			
0, 1	7613				
1, 2	7571				
0, 1	7567				
2, 3	7531				
1, 2	7525				
2, 3	7484				
0, 0	6946	6942.6	Q_1	7028	P_1
1, 1	6930	6928.6	Q_1	7006	P_1
0, 0	6908	6919.8	Q_2	7035	P_2
1, 1	6891	6902.6	Q_2	7005	P_2

CaH (contd.)

6346 A. B-SYSTEM, B $^2\Sigma \rightarrow ^2\Sigma$, ground state.

Bands degraded to the violet. Occurrence similar to A-System.

v', v''	Origins	Heads	
2, 2	6358		
1, 1	6352		
0, 0	6346	6389.3 P ₁	6382.1 P ₂

3534 A. C-SYSTEM, C $^2\Sigma \rightarrow ^2\Sigma$, ground state.

Bands degraded to the violet forming fairly sharp P heads. Complete system observed at high pressures of hydrogen (3-4 atms.).

v', v''	P. Heads	v', v''	P. Heads
0, 1	3696.6	1, 0	3367.6
0, 0	3533.6	2, 1	3356.3
1, 1	3515.4	3, 2	3346.5
2, 2	3498.1	4, 3	3337.6
3, 3	3482.0	5, 4	3330.8

4500 A. D-SYSTEM, D $^2\Sigma \rightarrow ^2\Sigma$, ground state.

Bands degraded to the red. System less intense than A and B. The R heads very weak.

v', v''	Origins	v', v''	Origins
0, 3	5301	1, 1	4473
0, 2	4988	1, 0	4235
1, 2	4732	2, 0	4059
0, 1	4702		

4900 A. E-SYSTEM, $^2\Pi \rightarrow ^2\Sigma$

Weak system slightly degraded to the violet. Observed in arc in hydrogen at low pressure with water-cooled copper cathode and anode of metallic calcium.

v', v''	Origin	Heads	
0, 0	4900	4898.1 Q ₁	4899.1 Q ₂
1, 1		4915.7 Q ₁	4916.6 Q ₂
2, 2		4934.8 Q ₁	4935.8 Q ₂

CaI

There are bands in the red and violet attributed to CaI, and a few weak bands in the ultra-violet.

RED BANDS

Occurrence. In absorption and in a flame.*Appearance.* Marked close sequences, degraded to the violet.*References.* K. Hedfeld, *Z.P.*, 68, 610. (1931).O. H. Walters and S. Barratt, *P.R.S.*, 118, 120. (1928)†.The bands have been analysed by Hedfeld into three overlapping systems with the same final levels. These systems are denoted by I, II and III, and the intensities I_a and I_f are given for absorption (Walters and Barratt) and emission in a flame.

CaI (*contd.*)

λ	I_a	I_f	Sequence	λ	I_a	I_f	Sequence
6513.7	1	0	0, 1 Q I	6388.8	10	9	0, 0 Q II
6488.7	1	0	0, 1 Q II	6363.2		0	0, 0 P III
6460.2	1	0	0, 1 Q III	6361.3	6	3	0, 0 Q III
6419.3		1	0, 0 P I	6315.4	8	0	1, 0 Q I
6412.9	10	6	0, 0 Q I	6291.9	6	0	1, 0 Q II
6392.7		0	0, 0 P II	6265.1	8	0	1, 0 Q III

VIOLET BANDS.

Occurrence. In absorption and in a flame.

Appearance. Close sequences degraded to the red.

References. C. M. Olmsted, *Z. wiss. Photogr.*, **4**, 255. (1906).

O. H. Walters and S. Barratt, *P.R.S.*, **118**, 120. (1928).

Strong bands compiled from the above references. Intensities I_a and I_f for absorption and flame.

λ	I_a	I_f
4334	1	3
4308		2
4289	5	4
4255	1	3
4250	0	2
4211	2	4
4176		2

ULTRA-VIOLET BANDS.

Observed in absorption by Walters and Barratt. Degraded to shorter wavelengths.

λ	I
3266	0
3215	3
3186	3
3158	1
3127	1

CaO

When calcium salts are introduced into a flame or arc strong band systems are observed in the infra-red, extreme red, orange and green, and in an arc or hollow cathode discharge there are several weaker systems in the blue, violet and near ultra-violet. The bands in the green and orange are attributed by Mahanti and by King to Ca_2 , but this assignment is contrary to our experience, which indicates CaO as the emitter. Brodersen apparently includes the green system in his term scheme for CaO , but omits the orange bands. Further work on these orange and green systems, which appear very readily and are a frequent impurity in arc and flame spectra, seems desirable; a rotational analysis made from large dispersion spectrograms might give conclusive results.

INFRA-RED SYSTEM

Appearance. Degraded to the violet. Three close sequences have been observed.

Reference. W. F. Meggers, *Bur. Stand. Jour. Res.*, **10**, 669. (1933).

INDIVIDUAL BAND SYSTEMS

109

CaO (contd.)

λ	I	v', v''	λ	I	v', v''
10533	3	0, 0	9807.3	20	2, 1
10492	4	1, 1	9775.0	15	3, 2
10444.7	5	2, 2	9741.0	5	4, 3
10396.7	6	3, 3	9700.0	10	5, 4
10339.8	5	4, 4	9229	20	2, 0
10289.5	5	5, 5	9215.1	5	3, 1
9834.7	30	1, 0	9193.4	2	4, 2

EXTREME RED SYSTEM

References. W. F. Meggers, see above.

P. H. Brodersen, *Z.P.*, **79**, 613. (1932) †; and *Z.P.*, **104**, 135. (1936).

The analyses proposed by Meggers and by Brodersen differ in detail. The near equality between ω' and ω'' results in some uncertainty in the assignment of vibrational quantum numbers. The following measurements are compiled from the above references, intensities where given being by Meggers.

λ	I	λ	I	λ	I	λ	I
8651.9	20	8153.0	40	7327.7	2	6968.6	2
8643.0	2	7721.1	4	7318.5	3	6956.0	2
8629.2	1	7715.7	5	7308.4	2	6639.2	
8167.0	5	7339.0		6983.2	3	6625.0	

ORANGE SYSTEM

Occurrence. These bands occur very strongly and with great persistence when calcium salts are introduced into an arc in air. A. S. King (*Astrophys. J.*, **27**, 353 (1908)) reports that bands occur in a furnace spectrum of calcium in hydrogen and therefore concludes that they are due to Ca_2 or CaC . This is contrary to our experience; the bands do not occur with calcium chloride in an arc in hydrogen, and in view of the affinity of metallic calcium for water it is difficult to be sure that a little CaO was not present in King's experiments.

Appearance. A complex system of bands with heads degraded in each direction. See Plate I.

The following are the most prominent features, being rough measures from our plates taken in the second order of a 20-ft. concave grating. The letters R, V or M indicate direction of degradation of the head.

λ	I	λ	I	λ	I
6362	M 4	6183	V 6	6065	R? 5
6344	M 4	6097	V 10	6056	R 5
6318	M 2	6092	V 6	6041	R 3
6281	M 3	6088	R? 5	6006	V 8
6278	V 4	6075.5	V 5	6003	R 8
6262	M 8	6069	V 7	5983	R 8
6258.5	V 9				

GREEN SYSTEM

Occurrence. As for orange system.

Appearance. A diffuse banded structure, apparently without rotational fine structure, extending from 5473 A. to about 5560 A. Under small dispersion the

CaO (*contd.*)

appearance is of a diffuse band with head at 5473 Å. degraded to the red. Under large dispersion the head is less obvious, but there are maxima of intensity at about λ 5506, 5498, 5496, 5492, 5488, 5484, 5476 and 5473; the head at λ 5498 is relatively strong and appears to be shaded to the red. See Plate 1.

J. M. Lejeune and B. Rosen (*Bull. Soc. roy. Sci. Liège*, 317 (1945)) have made an analysis of the Orange and Green systems.

BLUE SYSTEM

Occurrence. Weak bands in the blue and violet are observed in flames and arcs into which calcium salts are introduced; the bands have also been observed in a hollow cathode discharge.

Appearance. Degraded to the red.

References. P. C. Mahanti, *P.R.*, 42, 609. (1932)†.

P. H. Brodersen, *Z.P.*, 104, 135. (1936-37).

Mahanti has analysed the bands into a single system; the observed and calculated band heads agree to about one wave-number and the listed intensities are quite smooth, but the published spectrograms do not inspire confidence. Brodersen has analysed the bands into several systems and his wave-lengths differ considerably from Mahanti's, but in the absence of published photographs or even estimated intensities it is difficult to compare the merits of the two papers. Further work on these bands is desirable.

The following are the strongest bands as observed by Mahanti; intensities on a scale of 6. Asterisks indicate that these bands have also been observed by Brodersen.

λ	<i>I</i>	λ	<i>I</i>	λ	<i>I</i>
4519.1	3	4366.7	5	4126.0	3
4505.0	4	*4351.2	5	*4104.1	4
4425.8	3	*4240.8	3	*4084.3	5
*4403.9	6	4221.9	5	*3973.9	3
*4384.8	6	*4205.1	6	*3872.9	2

ULTRA-VIOLET SYSTEM

Occurrence. As for blue system. These bands are stronger and more definite than those in the blue.

Appearance. Degraded to the red.

References. See blue system.

The following measurements are by Mahanti. Strongest bands:—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3753.2	3	0, 3	3494.7	3	1, 1
3676.5	3	1, 3	3475.0	6	0, 0
3656.6	4	0, 2	3409.1	4	1, 0
3583.7	3	1, 2	3346.7	3	2, 0
3564.0	5	0, 1	3287.4	3	3, 0

Note added in Proof.

J. M. Lejeune and B. Rosen (*Bull. Soc. roy. Sci. Liège*, 322 (1945)) have recently discussed the spectrum of CaO, and have given a vibrational analysis for the Blue system and revised the measurements and analysis for the Ultra-violet system. The following are the strongest heads:—

CaO (*contd.*)Blue or ϵ System

4204.5 (0, 2), 4105.3 (1, 2), 4083.8 (0, 1), 3968.5 (0, 0).

Ultra-violet or ζ System3872.5 (1, 4), 3853.8 (0, 3), 3773.2 (1, 3), 3753.0 (0, 2), 3656.1 (0, 1), 3563.5 (0, 0),
3495.0 (1, 0).**CbO***Reference.* V. Ramakrishna Rao, *Curr. Sci.*, **18**, 168, (1949).Red-degraded bands in columbium arc in air or in heavy-current discharge through CbCl_5 vapour gives two systems 6500–5600 and 5600–4200.Strongest heads $\lambda\lambda$ 5228.7, 4915.1, 4689.1, 4510.8 and 4369.7.**Cd₂**Several papers have appeared on the emission, absorption and fluorescence spectra of cadmium and there has been some controversy on the origin of the various bands which have been observed. The bands and continua produced by the Cd_2 molecule have been listed by Cram.*Reference.* S. W. Cram, *P.R.*, **46**, 205. (1934). λ 2124

A narrow band between 2140 and 2110 Å. has been observed in emission (in discharge tubes, especially ring discharges), absorption and fluorescence.

 λ 2212

A narrow band has been observed at 2212 Å. in absorption ; it is probably due to an impurity.

 λ 2288

A broad band with maximum at 2288 Å. has been observed in emission, absorption and fluorescence ; flutings are superposed on the red side of this. The limits and regions of the flutings are roughly :—

Source	Limits	Region of Fluting
Emission . . .	2191–3050	—
Absorption . . .	2212–3050	2590–2825
Fluorescence . . .	2260–3050	2700–3050

 λ 3178

Narrow band at 3178 in emission, absorption and fluorescence.

 λ 3261

Band overlapping Cd line at 3261, in emission, absorption, and fluorescence.

BLUE REGION

Broad band observed in emission and fluorescence.

Emission . . . 4058–5400 Å.

Fluorescence . . . 3800–5000 Å., maximum at 4000 Å.

CdBr

Bands have been obtained with discharges in CdBr_2 vapour extending from the infra-red to the near ultra-violet. Two systems have been described.

References. K. Wieland, *Helv. Phys. Acta.*, **2**, 46. (1929).

E. Oeser, *Z.P.*, **95**, 699. (1935).

SYSTEM $\lambda\lambda 8100-3500$

Occurrence. With CdBr_2 in low pressure discharge tubes (Wieland) and in fluorescence of CdBr_2 (Oeser).

Appearance. Diffuse bands degraded to the red on a continuous background with pronounced intensity maximum at 8000 Å.

Transition. ${}^2\Sigma \rightarrow {}^2\Sigma$, ground state.

SYSTEM $\lambda\lambda 3247-3123$

Occurrence. In discharge tubes (Wieland).

Appearance. Bands degraded to shorter wave-lengths.

Heads of strongest sequences :—

λ	I	Sequence
3223.4	4	0, 2
3199.9	8	0, 1
3176.6	9	0, 0
3151.3	7	1, 0
3126.5	2	2, 0

Bands $\lambda\lambda 3551-3407$ observed by Walter and Barratt (*P.R.S.*, **122**, 201 (1929)) in absorption are apparently the same as the thallium bromide bands, TlBr .

 CdBr_2

No bands are now attributed to CdBr_2 . The bands previously ascribed to this molecule by Wieland are emitted by CdBr . In absorption, continua have been observed by Oeser (*Z.P.*, **95**, 699. (1935)).

 CdCl

References. J. M. Walter and S. Barratt, *P.R.S.*, **122**, 201. (1929).

K. Wieland, *Helv. Phys. Acta.*, **2**, 46. (1929).

E. Oeser, *Z.P.*, **95**, 699. (1935).

S. D. Cornell, *P.R.*, **54**, 341. (1938).

H. G. Howell, *P.R.S.*, **182**, 95. (1943).

C. Ramasastry, *Indian J. Phys.*, **21**, 265. (1947)†.

BANDS $\lambda\lambda 8700-3300$. Diffuse bands, mostly degraded to the red, on a continuum with intensity maximum at 8500 Å. have been obtained with CdCl_2 in low pressure discharge tubes (Wieland). They are assigned to the transition ${}^2\Sigma \rightarrow {}^2\Sigma$, ground state. A further group of twenty-three bands $\lambda\lambda 4770-4050$, degraded to the red, has been obtained by Ramasastry in this region.

Strongest bands from Ramasastry :—

λ	I	λ	I	λ	I
4367.8	4	4455.0	5	4542.5	7
4395.6	4	4483.5	6	4572.1	6
4425.9	5	4514.5	6	4605.7	4

CdCl (*contd.*)

Bands $\lambda\lambda 3400-3300$. A set of bands degraded to shorter wave-lengths has been observed in this region by Wieland. They were not obtained by Ramasastry.

BANDS $\lambda\lambda 3181-3115$ and $\lambda\lambda 3104-3018$. These bands have been observed in absorption by Walter and Barratt and by Oeser. Howell assigns them to the transition ${}^2\Pi \rightarrow {}^2\Sigma$, ground state.

Strongest absorption bands recorded by Walter and Barratt :—

λ	I	λ	I	λ	I
3181	5	3163	3	3066	4
3174	2	3074	2	3060	3
3172	5	3072	5	3054	2

These bands were also observed in absorption by Oeser but were not obtained in emission by Ramasastry.

BANDS $\lambda\lambda 2240-2185$. Weak bands degraded to the red have been observed in high frequency discharges by Cornell and by Ramasastry. Transition probably ${}^2\Sigma \rightarrow {}^2\Sigma$.

Strongest bands from Ramasastry :—

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
2191.9	4	1, 0	2219.9	6	0, 1	2239.9	5	1, 3
2205.0	10	0, 0	2223.6	5	1, 2	2252.5	1	0, 3
2207.4	8	1, 1	2236.1	4	0, 2	2256.3	2	1, 4

BANDS $\lambda\lambda 2163-1774$. Twelve absorption bands have been observed by Oeser.

CdF

The absorption spectrum of the vapour produced by heating CdF_2 in a carbon-tube electric furnace has been investigated by C. A. Fowler. With low dispersion, covering the range 7000–1950 Å., narrow regions of absorption were observed near $\lambda 2800$ at a temperature of 1350°C . These increased in strength with rising temperature up to 1600°C ., but at higher temperatures were covered by continuous absorption spreading from shorter wave-lengths. High dispersion showed six bands degraded to the red, spaced almost equally, with intensities decreasing toward shorter wave-lengths. The two strongest have very diffuse heads; the remainder increase in sharpness toward the ultra-violet. The third, fourth and fifth bands have weak satellite heads. A narrow continuum with maximum at $\lambda 2824$ and a further group of three closely spaced heads apparently not belonging to the main system were also reported.

Reference. C. A. Fowler, *P.R.*, **62**, 141. (1942)†.

Fowler gives the following wave-lengths for the band heads of CdF in absorption together with tentative values of $v'-v''$:—

Main Heads		Satellite Heads	
λ	$v'-v''$	λ	$v'-v''$
2925.5	0		
2880.6	1		
2838.5	2	2837.2	2
2797.1	3	2796.0	3
2756.3	4	2755.5	4
2716.2	5		

CdF (*contd.*)

Unclassified Heads

 λ

2788.2

2786.5

2784.9

CdH*Reference.* E. Svensson, *Z.P.*, **59**, 333. (1930).4500 A. SYSTEM, A ${}^2\Pi \rightarrow {}^2\Sigma$, ground state.

Bands degraded to the violet, each with P, Q and R branches. The system is easily obtained in discharges where cadmium vapour is mixed with hydrogen. See Plate 4.

${}^2\Pi_{1/2} \rightarrow {}^2\Sigma$				${}^2\Pi_{3/2} \rightarrow {}^2\Sigma$			
v', v''	Origins	P Heads	Q Heads	v', v''	Origins	P Heads	Q Heads
0, 4	5624			0, 2	4835		
0, 3	5368	5368.7	5359.3	1, 3	4693		
1, 4	5146	5146.1	5141.2	0, 1	4571		
0, 2	5080	5081.7	5071.1	1, 2	4470		
1, 3	4926			0, 0	4300	4313.3	4297.6
0, 1	4791	4791.1*	4777.4	1, 1	4247		
1, 2	4683			1, 0	4026	4026.7	4008.5
0, 0	4500	4509.0	4491.3	2, 1	3980	3980.4	3965.6
1, 1	4437			2, 0	3789		
1, 0	4198	4198.6	4177.3				

* Line-like head.

Note. The values of λ given to 0.1 A. were taken from the rotational analysis ; other values from the energy-level diagram.

3520 A. SYSTEM, B ${}^2\Sigma \rightarrow {}^2\Sigma$, ground state.

Bands showing double P and double R branches degraded to the red.

v', v''	Origins	R Heads	v', v''	Origins	R Heads
0, 0	3520	3524.3	4, 0	3174	3174.3
1, 0	3420	3422.4	5, 0	3105	
2, 0	3332	3332.2	6, 0	3042	3042.9
3, 0	3249	3249.8	7, 0	2980	2985.6

4930 A. SYSTEM, C ${}^2\Sigma \rightarrow A {}^2\Pi$

Obtained under the same conditions as above. Band degraded to the red.

Q Head

4933.6

CdH⁺*References.* E. Svensson and F. Tyrén, *Z.P.*, **85**, 257. (1933).E. Bengtsson and R. Rydberg, *Z.P.*, **57**, 648. (1929).2341 A. SYSTEM, ${}^1\Sigma \rightarrow {}^1\Sigma$

Extensive system of singlet bands degraded to the red. System occurs with cadmium arc in hydrogen at low pressure ; and in discharges through a mixture

CdH⁺ (*contd.*)

of hydrogen and cadmium vapour where ionisation is favoured, such as hollow cathode or high-frequency discharge.

λ	I	v', v''		I	v', v''
2239.8	4	3, 1		2481.4	6, 2, 3
2275.2	5	1, 0		2538.2	8, 0, 2
2340.9	8	0, 0		2558.5	8, 1, 3
2437.9	10	0, 1		2574.8	7, 2, 4
2461.3	8	1, 2		2587.3	4, 3, 5

CdI

- References.* A. Terenin, *Z.P.*, **44**, 713. (1927).
 K. Wieland, *Helv. Phys. Acta.*, **2**, 46. (1929).
 K. Wieland, *Helv. Phys. Acta.*, **2**, 77. (1929).
 E. Oeser, *Z.P.*, **95**, 699. (1935).
 T. S. Subbaraya, N. A. N. Rao and B. N. Rao, *Proc. Indian Acad. Sci.*, **5**, 372. (1935)†.
 K. Wieland and A. Herczog, *Helv. Chim. Acta.*, **39**, 1702. (1946).
 H. G. Howell, *P.R.S.*, **182**, 95. (1943).
 C. Ramasastry and K. R. Rao, *Indian J. Phys.*, **20**, 100. (1946).

The bands fall into four groups :—

BANDS $\lambda\lambda 6600-3600$. Obtained in low pressure discharge tubes containing CdI₂ (Wieland, Ramasastry and Rao) and in fluorescence of CdI₂ (Terenin, Oeser). Diffuse, line-like bands on a continuum with pronounced intensity maximum at 6500 Å. The vibrational structure appears more clearly when CdI₂ is excited in the presence of a large excess of an inert gas. Transition ${}^2\Sigma \rightarrow {}^2\Sigma$, ground state. The frequency of the ground state, obtained from a vibrational analysis by the Indian authors, does not agree with that obtained for the ultra-violet bands.

BANDS $\lambda\lambda 3600-3500$. A group of three bands, 3585.8 (2), 3563.5 (4), 3541.0 (6), degraded to the violet

BANDS $\lambda\lambda 3500-3250$. Obtained in emission, in absorption and in fluorescence. Wieland measured about 90 bands degraded to the violet. Ramasastry has obtained additional bands at the ultra-violet end of the system. Transition possibly ${}^2\Pi_{3/2} \rightarrow {}^2\Sigma$, ground state. Howell suggests that the group of three bands given above may belong to the ${}^2\Pi_{1/2} \rightarrow {}^2\Sigma$, transition.

Heads of strongest sequences :—

λ	I	Sequence
3404.8	5	0, 1
3384.4	7	0, 0
3362.2	5	1, 0
3340.8	3	2, 0

BANDS $\lambda\lambda 2550-2350$. A number of weak bands degraded to the red have been observed by Wieland and by Ramasastry and Rao. Previously ascribed to CdI₂ by Wieland, the bands have now been interpreted as a ${}^2\Sigma \rightarrow {}^2\Sigma$, transition to the ground state. Wieland gives 27 bands and Ramasastry and Rao 56, with considerable differences in wave-lengths and intensities.

CdI (*contd.*)

Strongest heads with analysis given by Ramasastry and Rao :—

λ	I	v', v''	λ	I	v', v''
2441.7	3	1, 6	2399.6	3	3, 3
2425.5	3	2, 5	2389.7	3	3, 2
2415.6	3	2, 4			

Bands $\lambda\lambda 4301-3806$ reported in absorption by Walter and Barratt (*P.R.S.*, **122**, 201 (1929)) appear to be due to thallium and bismuth iodides, TII and BiI.

CdS

Continuous absorption.

Reference. P. K. Sen Gupta, *P.R.S.*, **143**, 438. (1933-4).

CeO

Occurrence. Cerium oxide or chloride in arc.

Appearance. All bands are degraded to longer wave-lengths.

Reference. W. W. Watson, *P.R.*, **53**, 639. (1938).

SYSTEM A.

Single-headed bands :—

$\lambda 8396$ head of (0, 1) sequence.

$\lambda 7879.3$ (1, 1) band.

$\lambda 7831.8$ head of strong (0, 0) sequence.

$\lambda 7380$ head of (1, 0) sequence.

SYSTEMS B AND C

These overlap and appear as a double-headed system.

$\lambda 7716$ head of (0, 1) sequence of System B.

$\lambda 7347$ (1, 1) band of System C.

$\lambda 7297.2$ (0, 0) sequence of System C.

$\lambda 7275.5$ (1, 1) band of System B.

$\lambda 7235.8$ (0, 0) sequence of System B.

$\lambda 6847$ (1, 0) sequence of System B.

SYSTEMS D AND E

$\lambda 4863.2$ (0, 0) sequence of System D.

$\lambda 4791.7$ (0, 0) sequence of System E.

$\lambda 4683$ (1, 0) sequence of System D.

$\lambda 4614$ (1, 0) sequence of System E.

Cl₂**ABSORPTION SPECTRUM**

Chlorine gas shows a strong continuous absorption extending from the blue to around 2500 A. and having a maximum around 3300 A.

In greater thicknesses (1 metre at atmospheric pressure) there is also a banded absorption spectrum extending from 4800 A. to the red. Full measurements of the individual lines of this system have been published by Laird and a vibrational and rotational analysis is given by Elliott. The bands are strongly degraded to the red and the bands do not show well-developed heads.

Cl_2 (contd.)

- References.* E. R. Laird, *Astrophys. J.*, **14**, 85. (1901).
 A. Elliott, *P.R.S.*, **123**, 629. (1929)†; **127**, 638. (1930).
 P. Venkateswarlu, *Proc. Indian Acad. Sci.*, **26A**, 22. (1947)†.

EMISSION SPECTRUM

The various emission spectra of chlorine as obtained in various sources have been summarised by Elliott and Cameron.

- References.* A. Elliott and W. H. B. Cameron, *P.R.S.*, **158**, 681. (1937).
 W. H. B. Cameron and A. Elliott, *P.R.S.*, **169**, 463. (1939).

Source	Spectrum	Observer
Discharge tube.	Bands 4871–3923 A.	Ota and Uchida.
Tesla discharge.	Continua; maxima 3070 A. and 2600 A.	Ludlam and West.
Positive point discharge.	Bands 4000–3100 A. Continua 2960 A., 2485 A.	Campetti.
Cl_2 in active nitrogen.	Continuum 2600–2540 A.	Strutt and Fowler.
Cl_2 burning in H_2 .	Bands 6500–5590 identical with absorption bands.	Kitagawa.
Cl_2 at high temperature.	Continuum in blue-green.	Kondratjew and Leipunski.
Discharge tube at high pressure.	Continua, max. 3070 and 2570 A.	v. Angerer.
High-frequency discharge.	Bands as for discharge tube; continua, max. 3063, 2957, 2881, 2819, 2758, 2714, 2564, 2432.	Elliott and Cameron.

The blue-violet emission bands obtained in ordinary discharge tubes, and high-frequency discharges have been attributed by Elliott and Cameron to the ionised molecule Cl_2^+ .

 Cl_2^+

Occurrence. Discharge tubes containing chlorine, including high-frequency discharge.

Appearance. Degraded to the red. Most of the bands are double-headed, probably due to isotope effect.

Transition. Probably ${}^2\Pi \rightarrow {}^2\Pi$.

- References.* Y. Ota and Y. Uchida, *Jap. J. Phys.*, **5**, 53. (1928)†.
 A. Elliott and W. H. B. Cameron, *P.R.S.*, **158**, 681. (1937)†.
P.R.S., **164**, 531. (1938).

The following are the strong bands as shown in the published photographs, with our estimates of intensity from these photographs. Measurements are from both Ota and Uchida and from Elliott and Cameron's first paper. For double bands only the first head is given. Elliott and Cameron do not agree with Ota and Uchida's vibrational analysis. The analysis given here, for those bands which have been identified, is Elliott and Cameron's. This is presumably checked by the rotational analysis, but the intensity distribution of the vibrational scheme is not very satisfactory. The letters i and ii denote the sub-system of the ${}^2\Pi \rightarrow {}^2\Pi$ transition to which the band belongs.

Cl_2^+ (contd.)

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
4870.9	7		4442.3	6		4194.7	7	
4853.9	7	8, 7 i	4421.5	6	5, 1 ii	4140.1	8	9, 2 i
4794.7	9	?	4407.5	6	6, 2 i	4112.8	6	8, 1 i
4751.0	9	4, 3 i	4381.0	5	5, 1 i	4041.7	7	
4682.6	10	5, 3 ii	4348.5	5	7, 2 ii	4033.0	7	
4613.6	9	4, 2 i	4316.0	7		3979.4	6	
4549.1	10	5, 2 ii	4285.6	6	6, 1 i	3961.4	5	9, 0 ii
4506.2	8		4252.4	5		3941.3	5	
4487.5	8	4, 1 i ?	4231.5	7	7, 1 ii			

CIF

Reference. A. L. Wahrhaftig, *J. Chem. Phys.*, **10**, 248. (1942).

The absorption of chlorine fluoride was examined over the range $\lambda\lambda 7000$ – 3500 and a system of bands found at $\lambda 4800$. Bands show single P and R branches degraded to the red. Suggested transition ${}^3\Pi_0 \rightarrow {}^1\Sigma$.

The following wave-lengths are for the origins of the bands except those marked *h*, which are for heads :—

λ	v', v''	λ	v', v''	λ	v', v''
4901.6	6, 0	4727.8	10, 0	4661.6	14, 0
4848.5	7, 0	<i>h</i> 4703.4	11, 0	4654.2	15, 0
4801.7	8, 0	<i>h</i> 4685.1	12, 0	<i>h</i> 4649.9	16, 0
4761.3	9, 0	<i>h</i> 4671.9	13, 0	<i>h</i> 4648.2	17, 0

The isotope effect was observed for the (8, 0), (9, 0) and (10, 0) bands.

Note added in Proof.

H. Schmitz and H. J. Schumacher, *Z. Naturforsch.* **2A**, 359 (1947)†, have given a modified analysis in which the v' numbering is 3 units lower.

CIF₃

Reference. H. Schmitz and H. J. Schumacher, *Z. Naturforsch.* **2A**, 363, (1947).

Absorption bands increasing in strength towards shorter wave-lengths. $\lambda\lambda 3412$, 3291, 3210, 3100, 3009, 2908, 2807, 2706, 2630, 2578, 2545, 2575, 2500, 2485, 2460, 2409, 2404, 2360, 2305, 2296, 2231.

ClO

Occurrence. In oxy-hydrogen flame to which Cl_2 has been added.

Appearance. Degraded to the red. The bands have complex heads, which are difficult to measure exactly.

Reference. G. Pannetier and A. G. Gaydon, *Nature, Lond.*, **161**, 242. (1948)†.

The following are the strongest heads ; a provisional vibrational analysis has been made.

λ	I	λ	I	λ	I
4459	3	4154	4	3874	10
4417	3	4114	9	3841	10
4373	3	4078	6	3761	9
4283	7	3991	8	3729.5	7
4241	5	3957	7	3652.5	6

ClO₂

Occurrence. Absorption by chlorine dioxide.

Appearance. Degraded to the red. This is, for a triatomic molecule, a remarkably regular system of well-defined single-headed bands. The bands are strongest in the region 3700 Å. to 3200 Å., but extend as far as the blue when sufficient thickness of gas is used. The bands occur in regularly spaced groups, each group consisting of one strong band and two or three weaker bands to the shorter wave-length side.

References. C. F. Goodeve and C. P. Stein, *Trans. Faraday Soc.*, **25**, 738. (1929)†.
H. C. Urey and H. Johnston, *P.R.*, **38**, 2131. (1931).
Z. W. Ku, *P.R.*, **44**, 376. (1933)†.

The following are the strong heads of the regularly spaced groups; these bands are accompanied by weaker bands to shorter wave-lengths, this being especially true of the bands at the visible end of the system. No intensities are available, but from Goodeve and Stein's published photograph it is seen that the band groups are very smooth in intensity distribution, the bands in the central region being the strongest.

λ4199·4, 4082·5, 3972·8, 3869·7, 3772·5, 3680·5, 3594·1, 3511·4, 3434·0, 3360·5, 3291·2, 3226·0, 3163·5, 3105·7, 3050·9, 2999·4, 2953·5.

CoBr or CoBr₂

Occurrence. Cobalt bromide in high-frequency discharge.

Reference. P. Mesnage, *Thesis for doctorate, Paris*. (1938).

The following are the strongest bands; bands degraded to the red, to shorter wave-lengths or headless bands showing only a maximum of intensity are denoted by the letters R, V or M:—

λ	I	λ	I	λ	I
5637·4 R	8	5528·3 R	7	4493·7 R	4
5558·2 R	5	5455 M	5	4462·3 R	4
5553·5 R	5	4749·2 R	6	4366·5 V	3
5547·0 R	6	4559·8 R	5	4337·9 R	6
5542·2 R	6	4540·9 R	4		

CoCl or CoCl₂

Occurrence. Cobalt chloride in high-frequency discharge.

References. P. Mesnage, *C.R. Acad. Sci., Paris*, **201**, 389 (1935); and *Thesis for doctorate, Paris*. (1938).

K. R. More, *P.R.*, **54**, 122. (1938).

The following are the strongest bands from Mesnage; bands degraded to the red, to shorter wave-lengths or headless bands showing only a maximum of intensity are denoted by the letters R, V or M:—

λ	I	λ	I	λ	I
6216·6 V	4	5737·9 M	10	4833·4 R	6
6033·4 V	4	5669·8 V	8	4702·3 R	5
5843·1 V	4	5668·2 M	10	4541·2 R	5
5837·5 V	8	5667·0 M	5	4506·8 R	7
5832·2 V	5	5565·2 R	5	4352·7 R	5
5742·0 M	5				

More has analysed a number of bands between 4600 and 4200 Å. into three sub-systems corresponding to a transition between triplet states. The heads of the (0, 0) bands of the sub-systems are at λ4541·3, 4462·5 and 4353·0.

CoH

Reference. A. Heimer, *Z.P.*, **104**, 448. (1937).

4494 A. SYSTEM, ${}^3\Phi_4 \rightarrow {}^3\Phi_4$

Bands degraded to the red. P and R branches widely spaced and Q branch strong near the origin but quickly dying out with increasing rotation. Bands obtained with electric furnace (King's type).

v', v''	Heads	
	R	Q
0, 0	4477.9	4495.0
1, 0	4194.5	4206.3

CoO

Reference. L. Malet and B. Rosen, *Bull. Soc. roy. Sci. Liège*, **382**. (1945).

Red-degraded bands observed in an arc between cobalt electrodes.

λ	I	λ	I	λ	I	λ	I
9125	4	8204	2	7440	2	6651	3
8985	3	7935	4	7220	2	6532	4
8705	4	7685	4	6910	5	6340	2
8494	4	7500	2	6670	3	6305	1
8247	2						

CrCl

Bands in the region 2600 Å. observed by Mesnage in a high-frequency discharge through a heated quartz tube containing chromium chloride appear to be due to aluminium chloride. Mesnage also reported diffuse bands, perhaps due to CrCl_2 , in the red with maxima at $\lambda\lambda 6268-59, 6005$, and $5862-44$.

References. P. Mesnage, *C.R. Acad. Sci. Paris*, **201**, 389. (1935).

A. G. Gaydon and R. W. B. Pearse, *Nature, Lond.*, **141**, 370. (1938).

CrH

Reference. A. G. Gaydon and R. W. B. Pearse, *Nature, Lond.*, **140**, 110. (1937)†.

3675 A. SYSTEM

Band degraded to the violet obtained in the spectrum of a high-tension arc between chromium electrodes in a flame of hydrogen.

The band extends from a weak head at $\lambda 3700$ to about $\lambda 3625$ with a strong head at $\lambda 3675$.

CrO

Occurrence. Chromium salts in carbon arc, and flame.

Appearance. Degraded to red.

Reference. C. Ghosh, *Z.P.*, **78**, 521. (1932)†.

Strong bands only:—

λ	I	v', v''	λ	I	v', v''
6891.5	5	2, 4	5794.4	8	1, 0
6829.7	6	1, 3	5623.3	5	3, 1
6771.8	6	0, 2	5564.1	5	2, 0
6451.5	7	1, 2	5416.5	4	4, 1
6394.3	9	0, 1	5356.4	3	3, 0
6051.6	10	0, 0	5168.2	3	4, 0

Cs₂

Several systems have been observed in absorption, and some of them in fluorescence. The character and relative strengths of the various systems are best seen from the photographs shown by Loomis and Kusch.

References. R. Rompe, *Z.P.*, **74**, 175. (1932).

F. W. Loomis and P. Kusch, *P.R.*, **46**, 292. (1934)†.

The following are the most important features in absorption :—

A strong system around 10500 Å.

Diffuse bands, degraded to longer wave-lengths, in the near infra-red, heads $\lambda\lambda 8733, 8346, 8262$ and 8170.

Most intense system with origin at $\lambda 7667$. The following heads are recorded by Rompe :—

λ	<i>I</i>
7680	0
7670	1
7640	2
7610	3
7540	5

A weak system of ten sharp heads, degraded to the red, 7400–7230.

A strong system with heads degraded to the violet at $\lambda\lambda 7078, 7075, 7072$ and diffuse bands 7185 and 7128.

A sharp head, degraded to the red, at $\lambda 6250$ appears at rather high temperature. Also in fluorescence.

A system of moderate intensity around 4800 Å.

Bands associated with 4555, 4593 Cs doublet.

A group of heads of moderate intensity at $\lambda\lambda 3959, 3953, 3947, 3941$, degraded to shorter wave-lengths.

$\lambda 3920$, a weak head degraded to shorter wave-lengths.

Bands associated with 3889, 3877 Cs doublet.

CsBr

The heated vapour shows strong continuous absorption in the middle ultra-violet, which merges at the long-wave end into diffuse band structure.

Reference. K. Sommermeyer, *Z.P.*, **56**, 548. (1929).

CsCd

Barratt has studied the absorption spectra of mixed metallic vapours of the alkali-metals with zinc, cadmium and mercury. In most cases he observed diffuse bands, with a sharp head on the long wave-length side, extending to the violet as a weak continuum.

For CsCd he observed bands at $\lambda\lambda 5316$ and 5228.

Reference. S. Barratt, *Trans. Faraday Soc.*, **25**, 758. (1929).

CsF

Reference. A. D. Caunt and R. F. Barrow, *Nature, Lond.*, **164**, 753. (1949).

In absorption by heated vapour there is a strong narrow region of continuum around 2100 Å., with weak bands on the long wave-length side, extending at high temperature to 2710 Å.

CsH

Reference. G. M. Almy, and M. Rassweiler, *P.R.*, **53**, 890. (1938).

5500 A. SYSTEM, ${}^1\Sigma \rightarrow {}^1\Sigma$, Ground State.

A many-lined system, analogous to those of the other alkali hydrides, obtained in absorption from a mixture of hydrogen and caesium vapour at about 550° C.

Origins of the strongest bands :—

v', v''	λ	v', v''	λ
0, 2	6110.8	6, 0	5138.2
1, 2	6031.4	7, 0	5073.6
1, 1	5740.4	8, 0	5010.0
2, 1	5667.8	9, 0	4947.8
2, 0	5402.6	10, 0	4887.1
3, 0	5336.3	11, 0	4827.6
4, 0	5269.9	12, 0	4769.8
5, 0	5203.8	13, 0	4713.3

CsHg

Diffuse bands, degraded to the violet, observed in absorption by Barratt (see CsCd). Heads $\lambda\lambda$ 5343, 5222, 5112, 4932 and 4817. Mention is also made of sharp bands with heads at $\lambda\lambda$ 4991, 4984 and 4975.

CsI

The heated vapour shows strong continuous absorption in the near ultra-violet, which merges, at the long-wave end, into diffuse band structure in the violet.

Reference. K. Sommermeyer, *Z.P.*, **56**, 548. (1929).

CsZn

Diffuse bands, degraded to the violet, observed in absorption by Barratt (see CsCd). Heads $\lambda\lambda$ 5163 and 5126.

CuBr

Occurrence. Three systems of bands have been observed in flames and in absorption.

Appearance. Degraded to red. Marked sequences.

Reference. R. Ritschl, *Z.P.*, **42**, 172. (1927).

The following measurements are by Ritschl; only the strong bands forming the heads of the sequences are given. Intensities, which have been increased to a scale of 10, are for absorption.

SYSTEM A

λ	I	v', v''
5032.2	3	0, 2
4954.7	4	0, 1
4883.4	4	1, 1
4879.3	8	0, 0
4810.4	2	1, 0

CuBr (*contd.*)**SYSTEM B**

λ	I	v', v''
4461.9	4	0, 2
4400.9	4	0, 1
4341.1	10	0, 0
4288.6	7	1, 0
4237.8	4	2, 0

SYSTEM C

λ	I	v', v''
4379.3	6	0, 2
4320.5	4	0, 1
4262.8	8	0, 0
4210.2	6	1, 0
4159.3	5	2, 0

CuCl

Occurrence. Five systems have been observed in flames, in fluorescence and in absorption. They also appear when CuCl is introduced into active nitrogen, and in an arc. The bands frequently occur as impurities in flame spectra, especially of CO. Systems D and E have been observed in discharge tubes containing CuCl.

Appearance. All five systems are degraded to the red, and form marked sequences. The group of pairs of bands formed by systems D and E is quite characteristic. See Plate 10.

References. R. Ritschl, *Z.P.*, **42**, 172. (1927).

J. Terrien, *C.R. Acad. Sci. Paris*, **201**, 1029. (1935).

A. G. Gaydon, *P.R.S.*, **182**, 199. (1943)†.

The following measurements are by Ritschl; only the strong bands forming the heads of the sequences are given. Intensities I_a and I_f refer to absorption and emission in flames respectively, and are on a scale of 10 for the whole group of systems.

SYSTEM A

λ	I_a	I_f	v', v''
5380	2		0, 1
5262.3	4	6	0, 0
5152	2	3	1, 0

SYSTEM B

λ	I_a	I_f	v', v''
4982.2	4	2	0, 1
4885.4	6		1, 1
4881.5	8	4	0, 0
4788.5	5	2	1, 0

SYSTEM C

λ	I_a	I_f	v', v''
4949.8	5		1, 2
4946.1	4	1	0, 1
4851.2	6		1, 1
4846.9	8	3	0, 0
4755.7	5	1	1, 0

CuCl (*contd.*)**SYSTEM D, D $^1\Pi \rightarrow ^1\Sigma$, GROUND STATE**

λ	I_a	I_f	v', v''
4515.9	1	5	0, 2
4433.8	6	9	0, 1
4358.1	5		1, 1
4353.9	9	10	0, 0
4280.9	7	9	1, 0
4211.0	4	3	2, 0

SYSTEM E, E $^1\Sigma \rightarrow ^1\Sigma$, GROUND STATE

λ	I_a	I_f	v', v''
4493.8	4	5	0, 2
4414.1	5		1, 2
4412.4	6	8	0, 1
4333.2	10	9	0, 0
4261.7	7		2, 1
4258.9	8	7	1, 0
4187.9	6	3	2, 0
4119.9	5		3, 0

S. P. Sinha (*Curr. Sci.*, **17**, 208 (1948)) has recently reported a number of additional weak bands in a flame 4000–3500 Å.

CuF

References. R. Ritschl, *Z.P.*, **42**, 172. (1927).

L. H. Woods, *P.R.*, **64**, 259. (1943)†.

Occurrence. Three systems have been observed in absorption. The same three systems have also been obtained by Woods from a copper hollow cathode containing gaseous HF at 0.1 mm. pressure. System C has also been observed in an arc. The bands have been obtained weakly by heating CuF_2 in active nitrogen and may occur in flame sources.

Appearance. Marked sequences with vibrational structure degraded to the violet but rotational structure degraded to the red.

Strong bands as observed by Ritschl. Intensities, which are for absorption, have been increased to a scale of 8.

SYSTEM A

Transition. A $^1\Pi \rightarrow X^1\Sigma$, ground state.

λ	I	v', v''
5694.3	6	0, 0
5685.7	6	1, 1
5677.2	5	2, 2

SYSTEM B

Transition. B $^1\Sigma \rightarrow X^1\Sigma$, ground state.

λ	I	v', v''
5061.1	7	0, 0
5052.3	6	1, 1
4901.3	5	1, 0

CuF (contd.)**SYSTEM C**

Transition. $c\ ^1\Pi \rightarrow x\ ^1\Sigma$, ground state.

λ	I	v', v''
5086.4	2	0, 1
4932.0	8	0, 0
4926.8	6	1, 1
4781.9	4	1, 0

CuH

Six systems have been reported for CuH, of which the strongest is the 4280 A. system.

References. A. Heimer and T. Heimer, *Z.P.*, **84**, 222. (1933).

T. Heimer, *Z.P.*, **95**, 321. (1935).

4280 A. SYSTEM, $^1\Sigma \rightarrow x\ ^1\Sigma$.

Bands with single P and single R branches degraded to the red. R branches turn very near to the origin. Occurs in most sources where Cu vapour and hydrogen are present together. See Plate 4.

v', v''	Origins	R Heads
2, 3	4745.3	4734.1
1, 2	4701.5	4689.0
0, 1	4661.9	4648.4
2, 2	4387.4	4399.0
1, 1	4336.2	4327.7
0, 0	4288.6	4279.6
2, 1	4067.6	4061.9
1, 0	4011.5	4005.4
2, 0	3780.5	3776.3
3, 0	3586.2	3583.0

3804 A. SYSTEM, $^1\Sigma \rightarrow x\ ^1\Sigma$.

P and R branches degraded to the red.

v', v''	Origins	R Heads
1, 4	4800.9	
1, 2	4133.5	4127.4
0, 1	4094.6	4087.4
2, 2	3917.9	3914.3
1, 1	3848.4	3843.8
0, 0	3803.8	3798.6
2, 1	3660.8	
1, 0	3590.4	

3689 A. SYSTEM, $^1\Pi \rightarrow x\ ^1\Sigma$

P, Q and R branches degraded to the red.

v', v''	Origins	R Head	Q Head
0, 0	3688.0	3684.0	3689.2
0, 1	3960.6		

CuH (*contd.*)3576 A. SYSTEM, ${}^1\Pi \rightarrow x {}^1\Sigma$

P, Q and R branches degraded to the red.

v', v''	Origins	R Head	Q Head
0, 1	3830.8		
0, 0	3575.1	3572.2	3576.3

3500 A. SYSTEM, ${}^1\Pi \rightarrow x {}^1\Sigma$

P, Q and R branches degraded to the red.

v', v''	Origin	R Head
0, 0	3500.9	3497

2239 A. SYSTEM, ${}^1\Pi \rightarrow x {}^1\Sigma$ *Reference.* B. Grundström, *Z.P.*, **98**, 128. (1935)†.

Bands degraded to the red. Obtained in absorption.

v', v''	Origins	R Heads	Q Heads
0, 0	2239	2228	2239.2
1, 1	2242	2234	2242

CuI*Occurrence.* In flame spectra and on introduction of copper iodide vapour into active nitrogen. Also in absorption.*Appearance.* Degraded to red. Single-headed (apart from isotope shift). Close sequences.*Transition.* There are five systems of bands A,B,C,D, and E all to the ground electronic state.*References.* R. S. Mulliken, *P.R.*, **26**, 1. (1925).R. Ritschl, *Z.P.*, **42**, 172. (1927).

The strongest bands listed by Mulliken (in active nitrogen) are given in the following tables. Intensities have been increased to a scale of 10.

SYSTEM A

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
5494.1	3	4, 9	5312.4	5	2, 5	5117.3	3	3, 3
5477.1	4	3, 8	5297.5	6	1, 4	5101.9	3	2, 2
5461.3	3	2, 7	5283.8	4	0, 3	5072.8	10	0, 0
5402.2	5	3, 7	5241.0	3	2, 4	5034.6	3	2, 1
5386.5	6	2, 6	5226.1	5	1, 3	5019.7	7	1, 0
5371.5	5	1, 5	5212.2	7	0, 2	4983.9	4	3, 1
5357.4	3	0, 4	5155.8	3	1, 2	4968.3	5	2, 0
5328.5	3	3, 6	5141.1	7	0, 1	4919.1	3	1, 0

SYSTEM B

λ	<i>I</i>	v', v''
4607.1	3	2, 2
4601.6	3	1, 1
4596.9	3	0, 0
4446.8	2	1, 0

CuI (*contd.*)

SYSTEM C

λ	I	v', v''
4694.0	2	1, 3
4687.8	3	0, 2
4630.6	5 ?	0, 1
4575.1	4	0, 0
4527.9	4	1, 0

SYSTEM D

λ	I	v', v''	λ	I	v', v''
4514.8	3	0, 3	4369.9	3	1, 1
4471.6	3	1, 3	4359.9	4	0, 0
4462.2	4	0, 2	4320.0	3	1, 0
4410.8	5	0, 1			

SYSTEM E

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
4425.1	2	3, 8	4315.4	3	1, 4	4214.6	4	0, 1
4419.1	3	2, 7	4309.6	4	0, 3	4180.8	2	2, 2
4413.7	2	1, 6	4286.5	2	4, 6	4174.6	4	1, 1
4369.9	3	2, 6	4280.1	2	3, 5	4168.5	1	0, 0
4364.0	4	1, 5	4261.7	5	0, 2	4129.4	2	1, 0
4358.3	3	0, 4	4227.0	4	2, 3	4091.3	3	2, 0

CuO

Occurrence. Copper arc in air or oxygen; also copper salts in flame or in active nitrogen containing trace of oxygen. With exploded Cu wires.

Appearance. Degraded to longer wave-lengths. Widely spaced double-headed bands in orange.

References. H. Hertenstein, *Z. Wiss. Photogr.*, **11**, 69, 119. (1912).

R. S. Mulliken, *P.R.*, **26**, 1. (1925).

P. C. Mahanti, *Nature, Lond.*, **125**, 819. (1930).

F. W. Loomis and T. F. Watson, *P.R.*, **48**, 280. (1935).

J. M. Lejeune and B. Rosen, *Bull. Soc. roy. Sci., Liège*, **81**, (1945)

The analysis proposed by Mahanti is doubted by Loomis and Watson. The following are our own measurements made from a spectrogram of the flame above a copper arc taken on the first order of a 20-ft. concave grating spectrograph. The heads in the orange region are complex, consisting of from four to six close heads of varying strengths; only the outstanding heads are given. See Plate 10.

ORANGE REGION

Intensities I_a are for our spectrogram of the arc; intensities I_n are for active nitrogen, from Mulliken.

CuO (*contd.*)

λ	I_a	I_n	λ	I_a	I_n	λ	I_a	I_n
6547	—	2	6376.9	2*	0	6059.3	10	7
6530	—	1	6294.0	5	2	6045.1	9	1
6493.4	1	1	6280.9	1	0	5847.6	3	—
6430.0	3	3	6161.5	9	8	5832.7	2	—
6400.4	5	1	6146.8	8	2	5827.7	1	—

* Recorded as intensity 8 by Hertenstein.

According to Guntzsch, these bands belong to a ${}^2\Sigma \rightarrow {}^2\Sigma$ transition. Vibrational quantum numbers are assigned as follows:—

6161.9 (1, 1), 6147.3 (0, 0), 6060.8 (2, 1), 6045.0 (1, 0).

References. A. Guntzsch, *Nature, Lond.*, **157**, 662. (1946).

A. Guntzsch, *Ark. Mat. Astr. Fys.*, **33A**, No. 2. (1946).

GREEN REGION

There are a large number of weak bands in this region, including a little group of heads between 5237 and 5228 Å. and heads at 5344, 5313, 5308, 5279 and 5274 Å. Diffuse bands near 5350 Å. are a strong feature of flames containing copper compounds.

VIOLET REGION

Hertenstein obtained a number of bands in the violet region which he attributed to CuO. Lejeune and Rosen have also obtained some 25 bands in the region 5392–4179 Å. from exploded copper wires which agree in part with those of Hertenstein. These they have partly analysed.

Bands degraded red. Wave-lengths and intensities of the strongest bands from Hertenstein:—

λ	I	λ	I	λ	I
4917	5	4721	7	4532	5
4884	5	4712	7	4525	5
4864	5	4697	5	4518	5
4854	5	4688	5	4464	7
4829	4	4636	6	4457	8
4771	6	4584	6	4453	8

F₂

Occurrence. Discharge through fluorine.

Appearance. Degraded to the red. Four strong bands roughly equally spaced, and a few weaker bands.

Transition. ${}^1\Pi \rightarrow {}^1\Sigma$.

References. H. G. Gale and G. S. Monk, *Astrophys. J.*, **59**, 125 (1924)†; and **69**, 77. (1929)†.

J. Aars, *Z.P.*, **79**, 122. (1932)†.

The following wave-lengths are from Gale and Monk's first paper; the intensities are our estimates from the published photograph. Owing to perturbations the vibrational analysis is difficult, and that proposed by Gale and Monk is unconvincing, although no alternative is obvious.

F_2 (contd.)

λ	I	λ	I
6977.0	0	5851.3	4
6927.2	0	5731.4	9
6518.6	10	5515.5	0
6488.7	5	5393.9	7
6102.6	10	5102.2	2

FeBr or FeBr₂

Occurrence. High-frequency discharge through iron bromide vapour.

Reference. P. Mesnage, *C.R. Acad. Sci. Paris*, **204**, 761 (1937); and *Thesis for doctorate, Paris*. (1938).

The following are the strongest bands: R, V or M indicate that the band is degraded to longer or shorter wave-lengths or that the measurement is of the maximum. No analysis is given.

λ	I	λ	I
6435 V	15	6187 M	10
6400 R	15	6146 M	4
6302 M	6	6081 M	4
6293 V	5	3694 V	4

FeCl and FeCl₂

In high-frequency discharges through FeCl₂ there is complex band structure in the visible region, due to FeCl or FeCl₂, and better defined systems of FeCl at 3582 and 3447 Å. FeCl₂ shows continuous absorption with maximum at 2730 Å.

References. P. Mesnage, *C.R. Acad. Sci., Paris*, **201**, 389. (1935).

P. Mesnage, *Thesis, Paris*. (1938).

E. Miescher, *Helv. Phys. Acta.*, **11**, 463. (1938).

W. Müller, *Thesis, Basel*. (1943)†.

VISIBLE REGION

Strongest bands from Mesnage, who has made a provisional analysis into several systems. Letters R, V and M indicate degraded to red, violet and maximum of headless structure.

λ	I	λ	I	λ	I
6384.5 R	5	6056.5 V	6	5801.4 M	8
6378.0 R	5	5989.8 V	7	4885.5 M	8
6064.0 V	10	5989.4 V	6	4877.5 M	6
6060.2 V	7	5900.5 M	6	4863.4 R	5

3582 Å. SYSTEM

Degraded violet. Observed by Müller and attributed to a ${}^4\Pi \rightarrow {}^4\Sigma$ transition.

Heads of (0, 1) sequence $\lambda\lambda$ 3634.1, 3630.2, 3625.6, 3618.2.

Heads of (0, 0) sequence $\lambda\lambda$ 3582.8, 3579.2, 3574.6, 3567.3.

Heads of (1, 0) sequence $\lambda\lambda$ 3529.0, 3525.5, 3521.3, 3514.0.

3447 Å. SYSTEM

Degraded violet. Observed by Mesnage and Miescher. Transition probably

${}^6\Pi \rightarrow {}^6\Sigma$. Miescher gives the following heads of the (0, 0) sequence, $\lambda\lambda$ 3447.6, 3443.5, 3437.9, 3431.5, 3424.0, 3415.6. Among the other heads the following may be prominent, $\lambda\lambda$ 3463.4, 3412.8, 3397.3, 3381.9, 3374.8, 3366.8.

FeH

Reference. A. Heimer, *Naturwiss.*, **24**, 491. (1936).

4288 A. SYSTEM, $^1\Sigma \rightarrow ^1\Sigma$ (?) *

Band degraded to the red.

v', v''	Origin
0, 0	4288

* Heimer reports the band as being of the type $^1\Sigma \rightarrow ^1\Sigma$. If it is due to FeH the multiplicity should be even. FeH⁺ would be expected to give odd multiplicity.

FeO

Strong bands in the orange and infra-red are emitted by the flame of an iron in air and when iron carbonyl is introduced into a flame. These systems, and another weak system in the blue, are also emitted from exploding wires. The bands in the orange have been analysed into two systems A and B; the bands in the blue can be arranged into another system C; these three systems have a common ground level. The infra-red bands, system D, probably have the same initial level as system A.

References. A. G. Gaydon, *Ph.D. Thesis, London.* (1937)†.

A. Delsemme and B. Rosen, *Bull. Soc. roy. Sci., Liège*, **70**. (1945)†.

L. Malet and B. Rosen, *Bull. Inst. Roy. Colon. Belg.*, **377**. (1945)†.

ORANGE BANDS, SYSTEMS A AND B

The general appearance is complex. Most of the bands are degraded to the red, but some features (indicated by M) appear to be maxima of headless structures. In the following list, bands given with intensities are from Gaydon, while others are from Delsemme and Rosen. See Plate 9.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
6651.5		A 1, 4 i	6084.7		B 0, 1	5624.1	4	
6596.6		A 1, 4 ii	5974.6	6	A 1, 2 i	5621.3	4	
6566.7	2	A 0, 3 i	5934.8		A 1, 2 ii	5614.0	6	A 0, 0 i
6524.1	2	A 0, 3 ii	5919	4M		5582.8	6	A 0, 0 ii
6445.2		B 1, 3	5911	4M		5543.2	2	B 2, 1
6430.3		B 0, 2	5903.0	6	A 0, 1 i	5531.4	4	
6295.9		A 1, 3 i	5868.1	9	A 0, 1 ii	5527.9		B 1, 0
6278.9		A 1, 3 ii	5819.2	6	B 2, 2	5430	2	
6218.9	10	A 0, 2 i	5807.4	2	B 1, 1	5408.6		A 1, 0 i
6180.5	9	A 0, 2 ii	5789.8	9	B 0, 0	5382.1		A 1, 0 ii
6109.9	9	B 1, 2	5678.9		A 1, 1 i	5289.5		B 2, 0
6097.3	9M		5646.6	6	A 1, 1 ii			

BLUE SYSTEM, C.

From Malet and Rosen. Degraded red.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
4929	1	1, 3	4544	3	1, 1
4730	4	1, 2	4478	4	0, 0
4659	3	0, 1	4386	2	
4604	1	2, 2			

FeO (contd.)**INFRA-RED SYSTEM, D.**

Degraded to the red. The following measurements are by Malet and Rosen, with intensities, where given, by Gaydon whose observations cover only part of the region. Gaydon's measurements come about 5 Å. less than those given here. The vibrational analysis is not very convincing.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
9408			8578	6	1, 2	7527		2, 1
9333		1, 3	8302	8	3, 3	7428		
9258			8230	8		7265		
9200			8137*	8		7022		2, 0
9088		0, 2	8112	10	2, 2	6830		
8864			7775			6700		3, 0
8790		2, 3	7690		3, 2			

* From Gaydon.

Some of the bands not classified in the above list may fit into two other fragmentary systems.

GaBr

Occurrence. In high-frequency discharge and in absorption.

References. A. Petrikaln and J. Hochberg, *Z.P.*, **86**, 214. (1933)†.
E. Miescher and M. Wehrli, *Helv. Phys. Acta.*, **7**, 331. (1934).

SYSTEM A, $\lambda\lambda 3616-3452$

Not clearly degraded either way. (0, 0) band at $\lambda 5549\cdot 3$.

SYSTEM B, $\lambda\lambda 3568-3439$

Not clearly degraded either way. (0, 0) band at $\lambda 3503\cdot 3$.

SYSTEM C, $\lambda\lambda 2874-2667$

Diffuse bands. 2679 (0, 0), 2720 (0, 1), 2754 (0, 2).

GaCl

Occurrence. In high-frequency discharge and in absorption.

References. A. Petrikaln and J. Hochberg, *Z.P.*, **86**, 214. (1933)†.
E. Miescher and M. Wehrli, *Helv. Phys. Acta.*, **7**, 331. (1934)†.

SYSTEM A, $\lambda\lambda 3469-3253$

Degraded to shorter wave-lengths. Strongest bands :—

λ	I	v', v''
3426·5	3	0, 1
3384·4	6	0, 0
3340·2	3	1, 0

SYSTEM B, $\lambda\lambda 3430-3220$

Degraded to shorter wave-lengths. Strongest bands :—

λ	I	v', v''
3388·0	3	0, 1
3346·8	6	0, 0
3303·9	3	1, 0

GaCl (*contd.*)SYSTEM C, $\lambda\lambda 2700-2483$

Degraded to the red. Strongest bands :—

λ	I	v', v''
2536.5	6	0, 2
2513.3	8	0, 1
2490.6	10	0, 0
2483	8	1, 0

GaCl₂

W. Wenk (*Dissertation, Basel, 1941*) has observed absorption continua at 2275, 2130, 1990 and 1735 Å.

GaI

Occurrence. In high-frequency discharge and in absorption.

Reference. E. Miescher and M. Wehrli, *Helv. Phys. Acta.*, **7**, 331. (1934)†.

Bands 4140–3810 Å. divided into two overlapping systems.

System A (0, 0) at $\lambda 3911.4$, (3, 2) $\lambda 3893.0$.

System B (0, 0) at $\lambda 3862.6$.

GaO

Occurrence. Gallium in copper arc in air.

Transition. $^2\Sigma \rightarrow ^2\Sigma$.

Reference. M. L. Guernsey, *P.R.*, **46**, 114. (1934)†.

(0, 1) sequence degraded to red.

λ	I	v', v''
4006.9	7	0, 1
4004.8	8	1, 2 etc.

(0, 0) sequence degraded only slightly to red.

λ	I	v', v''
3889.3	10	0, 0

(1, 0) sequence degraded to violet.

λ	I	v', v''
3778.5	9	1, 0
3779.4	9	2, 1

GdO

Occurrence. Gadolinium chloride in oxy-hydrogen flame ; the bands do not appear well in an arc.

Appearance. Degraded to longer wave-lengths. At the blue end of the spectrum the sequences are well marked, but in the red the appearance is more confused.

Reference. G. Piccardi, *Gazz. chim. ital.*, **63**, 887. (1933)†.

The bands have been arranged into ten systems by Piccardi. The following appear from the published photographs to be the outstanding heads ; the intensities are our own estimate from these photographs.

GdO (contd.)

λ	<i>I</i>	Syst.	v', v''	λ	<i>I</i>	Syst.	v', v''
*6223.5	6	IX	1, 1	4892.2	7	II	0, 0
*6212.1	4	X	0, 0	4816.6	5	I	1, 2
6201.2	7	IX	0, 0	4798.5	5	I	0, 1
5911.3	4	VI	0, 0	4633.3	8	I	1, 1
5818.9	9	IV	1, 1	4615.6	10	I	0, 0
*5807.2	9	IV	0, 0	4498.8	4	I	3, 2
5698.6	6	III	1, 1	4480.5	4	I	2, 1
5681.2	8	III	0, 0	4462.6	4	I	1, 0
4909.8	6	II	1, 1				

* Watson (*P.R.*, 53, 639 (1938)) suggests that some of the sequences in the orange may be due to calcium chloride. He regards the sequences at $\lambda\lambda$ 4892.2 and 4615.6 as the most sensitive for GdO.

The rough measurements made by Rodden and Plantinga (*P.R.*, 45, 280 (1934)) show practically no agreement with the above.

GeBr

Occurrence. In discharge through vapour of germanium tetra-bromide.

Appearance. Degraded to shorter wave-lengths.

Transition. Probably ${}^2\Pi \rightarrow {}^2\Sigma$, ground state.

Reference. W. Jevons, L. A. Bashford and H. V. A. Briscoe, *Proc. Phys. Soc.*, 49, 532. (1937).

Bands in region 3259–2946.

Strongest heads : 2954.2 (1, 0), 2980.2 (1, 1), 2988.0 (0, 0), 3006.4 (1, 2), 3014.7 (0, 1), 3041.3 (0, 2), 3068.8 (0, 3).

GeCl

Occurrence. In discharge through vapour of GeCl_4 .

Appearance. Degraded to shorter wave-lengths.

Transition. Probably ${}^2\Pi \rightarrow {}^2\Sigma$, ground state.

Reference. W. Jevons, L. A. Bashford and H. V. A. Briscoe, *Proc. Phys. Soc.*, 49, 532. (1937).

Bands in region 3202–2848.

Strongest heads : 3059.8 (0, 1), 3007.0 (0, 2), 2971.2 (0, 1), 2936.0 (0, 0), 2891.2 (1, 0).

Also a continuum in region 2660–2510.

Note added in Proof.

Barrow and Lagerqvist (*Arkiv. f. Fysik*, 1, 221 (1949))† report a new system in a discharge through GeCl_4 or in active N_2 . The transition is probably ${}^2\Delta \rightarrow {}^2\Pi$. The general appearance is of two sub-systems with sequence heads at 3392 and 3500, degraded to the red, although some individual bands are degraded to violet. Outstanding heads and direction of degradation.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3500.3	7 V	0, 0 ii	3386.1	3 M	?
3501.5	10 R	0, 0 ii	3392.1	5 V	0, 0 i
3511.0	9 R	1, 1 ii	3392.7	9 R	0, 0 i
3521.1	7 R	2, 2 ii	3401.1	5 R	1, 1 i
3571.0	4 R	2, 3 ii	3440.0	2 R	0, 1 i

GeO

Occurrence. In flame surrounding arc containing GeO_2 and in discharge through mixture of oxygen and GeCl_4 vapour.

Appearance. Degraded to red.

Transition. Perhaps ${}^1\Pi \rightarrow {}^1\Sigma$.

Reference. W. Jevons, L. A. Bashford and H. V. A. Briscoe, *Proc. Phys. Soc.*, **49**, 543. (1937).

The spectrum extends from 3319 to 2442 Å. The R heads of the strongest bands are listed.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3048.8	5	0, 5	2730.0	8	0, 1
2989.9	5	1, 5	2683.0	8	1, 1
2963.0	7	0, 4	2659.4	3	0, 0
2908.1	8	1, 4	2614.4	5	1, 0
2881.7	10	0, 3	2571.8	5	2, 0
2804.2	10	0, 2	2531.1	5	3, 0
2779.7	6	2, 3	2492.2	5	4, 0

GeS

Two band systems, both degraded to the red, have been observed in absorption by Shapiro, Gibbs and Laubengayer. System A has also been obtained in emission by Barrow from a heavy-current uncondensed discharge through a mixture of sulphur, germanium oxide and aluminium.

References. C. V. Shapiro, R. C. Gibbs and A. W. Laubengayer, *P.R.*, **40**, 354. (1932).

R. F. Barrow, *Proc. Phys. Soc.*, **53**, 116. (1941)†.

SYSTEM A, $\lambda\lambda 3750$ – 2709

Appearance. Degraded to the red. The bands are evenly spaced and form short sequences. Heads due to Ge^{70}S , Ge^{72}S , and Ge^{76}S as well as those due to the most abundant molecule Ge^{74}S , were observed.

Strongest bands :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3574.1	e	2, 10	3275.3	3	0, 4	3014.4	7	1, 0
3506.3	e	2, 9	3216.1	4	0, 3	2982.1	2	2, 0
3485.2	e	1, 8	3158.8	3	0, 2	2949.3	7	3, 0
3440.9	e	2, 8	3103.0	6	0, 1	2917.9	6	4, 0
3419.8	e	1, 7	3067.5	8	1, 1	2887.6	7	5, 0
3356.6	e	1, 6	3048.9	5	0, 0	2858.2	4	6, 0
3336.3	1	0, 5	3033.1	8	2, 1			

The letter e in the intensity column indicates that the band has been observed only in emission.

SYSTEM B, $\lambda\lambda 2782$ – 2464

Strongest bands :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
2675.5	2	1, 3	2632.8	2	3, 3
2657.4	3	0, 2	2615.0	3	2, 2
2653.8	3	2, 3	2597.0	2	1, 1
2635.8	2	1, 2	2594.5	3	3, 2
2618.0	2	0, 1	2574.5	2	4, 2

GeSe

Occurrence. In emission from a discharge tube containing a powdered mixture of germanium oxide, aluminium and selenium.

Appearance. Bands degraded to the red, λ 3170– λ 3570.

Reference. R. F. Barrow and W. Jevons, *Proc. Phys. Soc.*, **52**, 534. (1940)†.

Strongest bands :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3474.3	9	0, 4	3306.7	9	1, 1
3427.7	8	0, 3	3292.0	5	0, 0
3382.1	7	0, 2	3263.0	9	1, 0
3336.5	10	0, 1	3235.1	9	2, 0

Barrow and Jevons also give a list of 28 bands which are possibly due to GeSe. The strongest of these are : λ 3057.1 (2?), 2922.9 (2?), 2918.4 (2), 2905.7 (2), 2890.1 (2), 2888.0 (2), 2876.3 (2), 2855.2 (2), 2839.5 (2), 2823.7 (3), 2806.4 (2), 2791.4 (2), 2775.7 (2).

GeTe

Occurrence. In a heavy current, uncondensed discharge through a silica tube containing a powdered mixture of germanium dioxide, aluminium and tellurium.

Appearance. Bands degraded to the red, showing well-marked sequences.

Reference. R. F. Barrow and W. Jevons, *Proc. Phys. Soc.*, **52**, 534. (1940)†.

The following are the strongest bands :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3708.3	8	0, 3	3553.4	7	1, 0
3665.2	9	0, 2	3526.3	7	2, 0
3636.3	6	1, 2	3500.0	6	3, 0
3622.6	10	0, 1	3475.4	5	4, 0
3594.3	10	1, 1	3449.9	4	5, 0
3581.1	5	0, 0	3424.6	3	6, 0
			3401.8	1	7, 0

H₂

Occurrence. In discharge tubes containing hydrogen or water vapour. The system frequently appears when a discharge tube is first evacuated, especially if it has metal electrodes which occlude hydrogen.

Appearance. The hydrogen molecular spectrum, or "secondary" spectrum of hydrogen as it is often called, has few characteristic features, as the rotational structure is so open that there are no heads or close groups of lines to form anything resembling the usual band structure. The system is strongest in the orange but extends throughout the whole visible spectrum. Identification is rendered easier by the almost invariable presence of the strong hydrogen atomic lines, H _{α} 6562.79, H _{β} 4861.33, H _{γ} 4340.47 Å. See Plate 4.

Reference. H. G. Gale, G. S. Monk and K. O. Lee, *Astrophys. J.*, **67**, 89. (1928).

The following are the strongest lines of the spectrum, listed as intensities, 8, 9, or 10 by Gale, Monk and Lee.

H_2 (contd.)

λ	λ	λ	λ	λ	λ
8349.52	6135.39	5878.50	5505.52	5039.82	4709.54
8273.26	6121.79	5849.32	5499.58	5030.37	4683.82
8164.64	6098.22	5836.13	5495.96	5015.07	4662.81
7524.64	6095.96	5822.76	5481.08	5013.04	4661.40
7253.28	6080.78	5812.59	5459.60	5011.19	4631.85
7195.66	6069.99	5806.10	5434.82	5007.99	4627.99
7168.81	6063.28	5775.05	5425.89	5003.40	4617.53
6428.11	6031.90	5736.88	5419.89	4973.31	4582.59
6399.47	6027.98	5731.92	5401.05	4934.24	4579.99
6327.06	6021.27	5728.55	5388.17	4928.79	4575.88
6299.42	6018.29	5689.19	5303.10	4928.64	4572.71
6285.39	6002.82	5655.75	5291.60	4873.01	4568.13
6238.39	5994.06	5634.81	5272.30	4856.55	4554.16
6224.81	5975.44	5612.54	5266.04	4849.30	4498.11
6201.18	5949.89	5597.64	5196.37	4822.94	4212.50
6199.39	5938.62	5552.53	5084.84	4763.84	4205.10
6182.99	5931.37	5537.47	5055.09	4723.03	4177.12
6161.60	5888.17	5518.47	5041.63	4719.04	4171.31
					4069.63
					4066.88

 HBr^+

Reference. F. Norling, *Z.P.*, **95**, 179. (1935).

3500 A SYSTEM, ${}^2\Sigma \rightarrow {}^2\Pi_3$, GROUND STATE

Widely-spaced doublet system obtained in hollow cathode discharge in hydrogen bromide. Degraded to the red.

${}^2\Sigma \rightarrow {}^2\Pi_3$				${}^2\Sigma \rightarrow {}^2\Pi_3$			
v', v''	Origins	Heads		v', v''	Origins	Heads	
		Q	R ₁₂			R ₁	Q ₁
0, 0?	3762	3760.3	3761.0	0, 0?	3421	3417.6	3420.5
1, 0?	3582	3581.5	3582.0	1, 0?	3272	3269.3	3271.8

HCN

INFRA-RED ABSORPTION

Occurrence. Absorption by hydrocyanic acid gas.

Reference. R. M. Badger and J. L. Binder, *P.R.*, **37**, 800. (1931).

This is the vibration-rotation spectrum. Each band shows P and R branches, but no Q branch has been observed. There is a band with origin at 7912 A.; the R branch is stated to close up to resemble a head, probably around 7880 A. There is a similar but weaker band with origin at 8563 A.

HCl

Reference. E. Lindholm, *Ark. Mat. Astr. Fys.*, **29B**, No. 15. (1943).

Two vibration-rotation bands are observed:—

$\lambda 9152$ (4, 0) and $\lambda 7463$ (5, 0).

HCl⁺

Reference. M. Kulp, *Z.P.*, **67**, 7. (1931).

3500 A. SYSTEM, ${}^2\Sigma \rightarrow {}^2\Pi_3$, GROUND STATE

An extensive system of bands in the region 2830–3966 Å. Bands are double and possess P, Q and R branches degraded to the red. The system occurs in low pressure discharges through pure hydrogen chloride.

v', v''	${}^2\Sigma \rightarrow {}^2\Pi_3$		${}^2\Sigma \rightarrow {}^2\Pi_3$	
	Origins	R Heads	Origins	R Heads
0, 1	3966.3	3955.7	3867.8	3853.6
0, 0	3599.5	3591.6	3518.1	3507.3
1, 0	3411.9	3405.8	3338.6	3330.0
2, 0	3250.9	3245.9	3184.5	3177.3

Continua. Kulp records also a weak continuum with a maximum of intensity at 3000 Å. and a second stronger continuum with a maximum at 2570–2580 Å.

HF⁺

Occurrence. Obtained with HF at 0.1 mm. pressure in copper hollow cathode.

Appearance. The spectrum was investigated over the range 7000–2000 Å. A band spectrum of widely spaced lines was observed in the region 2450–2600 Å. and attributed to a ${}^2\Sigma \rightarrow {}^2\Pi$ system of HF⁺.

Reference. L. H. Woods, *P.R.*, **64**, 259. (1943)†.

HNCO, Isocyanic acid

Occurrence. Absorption by vapour.

Reference. Sho Chow Woo and Ta Kong Liu, *J. Chem. Phys.*, **3**, 544. (1935).

Diffuse bands $\lambda\lambda$ 2565, 2545, 2528, 2513, 2505, 2495, 2477, 2465, 2445, 2434, 2415, 2400, 2385, 2370, 2357, and 2345.

Continuous absorption below 2240 Å.

HNO₂ ?

Occurrence. Melvin observed the bands in absorption by a mixture of nitric oxide, nitrous oxide and water vapour. Newitt and Outridge observed a probably identical system in self-absorption from explosions and flames of carbon monoxide mixed with nitric and nitrous oxides.

Appearance. A fairly regular system of narrow headless bands.

References. E. H. Melvin and O. R. Wulf, *J. Chem. Phys.*, **3**, 755. (1935)†.

D. M. Newitt and L. E. Outridge, *J. Chem. Phys.*, **6**, 752. (1938).

H. W. Thompson, *J. Chem. Phys.*, **7**, 136. (1939).

Melvin and Wulf attributed the bands to hydrogen nitrite HNO₂, while Newitt and Outridge assigned the bands to NO₂. Thompson expressed the opinion that the two systems were not the same, and that the former are NHO₂, while the latter are due to the carrier –NO₂.

In the following table the wave-lengths given by Newitt and Outridge (λ N & O) with intensities on a scale of 0 to 3, are compared with Melvin and Wulf's values (λ M & W) with our estimates of intensities made from the published spectrograms (on a scale of 10).

HNO₂? (contd.)

λ N & O	<i>I</i>	λ M & W	<i>I</i>	λ N & O	<i>I</i>	λ M & W	<i>I</i>
3845	1	3843	4	3485	1		
3800	0			3440	0		
3764	1			3418	3	3416	8
3726	2			3390	1	3388	4
3680	3	3681	9	3330	0		
3656	1			3305	0	3307	4
3615	0			3270	1	3278	2
3575	0			3202	0	3204	0
3545	3	3539	10	3183	0	3177	0
3513	1	3510	3				

H₂O

ATMOSPHERIC AND INFRA-RED ABSORPTION (VIBRATION-ROTATION SPECTRUM)

Occurrence. Absorption by water vapour, observed especially in solar spectrum by atmospheric absorption.

Appearance. Very complex bands, showing fairly open rotational structure, but no obvious heads.

References. W. Baumann and R. Mecke, *Z.P.*, 81, 445. (1933)†.

K. Freudenberg and R. Mecke, *Z.P.*, 81, 465. (1933).

The following are the origins of the bands :—

λ_0	$v'_\sigma v'_\pi v'_\delta$	λ_0	$v'_\sigma v'_\pi v'_\delta$	λ_0	$v'_\sigma v'_\pi v'_\delta$
9420	1, 2, 0	7227	1, 3, 0	5952	1, 3, 2
9060	3, 0, 0	6994	3, 1, 0	5924	1, 4, 0
8227	1, 2, 1	6524	1, 3, 1	5722	3, 2, 0
7957	3, 0, 1	6324	3, 1, 1		

The following are the strongest individual lines of each band :—

λ	<i>I</i>	λ	<i>I</i>	λ	<i>I</i>	λ	<i>I</i>
(9420)		9016.76	5	8162.36	8	6977.49	3
9543.93	8	9003.80	5	8161.43	8	6961.27	4
9522.30	9	9000.22	10			6956.41	4
9461.16	9	8991.88	7	(7957)		6943.81	3
9459.96	8			7901.78	3	(6524)	
9440.89	12	(8227)	8	(7227)		6543.91	2
9437.90	8	8287.94	7	7272.98	5	6533.95	2
9428.36	8	8282.03	8	7265.60	5	6516.63	2
9426.85	9	8274.35	8	7206.43	6	6514.74	2
9386.84	9	8256.52		7204.32	5	6495.86	2
9381.22	9	8228.31	8	7191.50	6	(6324)	
9377.74	9	8226.96	10	7187.39	5	very weak	
9371.58	9	8197.70	8	7186.38	5		
9344.05	10	8193.11	7			(5952 and 5924)	
		8189.27	8	(6994)	3	5941.08	5
(9060)		8176.97	10	7016.45	3	5932.09	5
9155.68	6	8170.00	8	6989.00		5924.27	4
9072.01	5	8164.54	10	6986.59	3	5919.65	7

H_2O (contd.)

λ	I	λ	I	λ	I
5919.06	6	5898.17	4	5719.58	1
5918.42	4	5885.98	5	5692.42	1
5914.22	6				
5901.42	6	(5722)			
5900.05	4	5737.69	1		

VISIBLE AND INFRA-RED EMISSION

This is part of the vibration-rotation spectrum of H_2O . The infra-red bands occur readily in flames, but the visible bands are very weak and are given best by a flame of oxygen burning in hydrogen. The system is complex and in the visible the maxima of intensity are probably due to bunching of lines of complex rotational structure and the heads are not very definite; to longer wave-lengths, however, some of the bands show sharp heads and are degraded to longer wave-lengths.

References. T. Kitagawa, *Imp. Acad. Tokyo Proc.*, **12**, 281. (1936)†.

A. G. Gaydon, *P.R.S.*, **181**, 197. (1942)†.

Bands in the visible (as far as 7000 Å.) are by Kitagawa, with intensities reduced to a scale of 5; measurements for the infra-red by Gaydon.

λ	I	λ	I	λ	I	λ	I
9669	7*	8916	7*	6468.0	5	5988.8	3
9610	4	8097	8*	6457.5	4	5948.8	3
9559	4	7299	5	6377.1	4	5923.8	2
9485	3	7164.5	6*	6321.6	4	5900.2	3
9440	3	6922.0	2*	6255.1	4	5880.2	3
9333	7	6628.6	4	6220.0	3	5861.6	2
9277	10*	6574.5	4	6202.6	4	5806.9	2
9183	4	6516.8	5	6181.5	2	5715.3	1
9129	4	6490.4	5	6165.7	4	5683.3	1
8974	3						

* Outstanding head, degraded to longer λ .

OTHER VISIBLE EMISSION BANDS

Schüler and Woeldike have obtained a number of bands with open structure degraded to the red in a discharge through water vapour which they attribute to H_2O .

Wave-lengths of heads:—

5480.2, 5125.6, 4730.6, 4587.3, 4336.6, 4216.4.

Reference. H. Schüler and A. Woeldike, *Phys. Zeits.*, **44**, 335. (1943)†.

FAR ULTRA-VIOLET ABSORPTION

References. S. Liefson, *Astrophys. J.*, **63**, 73. (1926)†.

G. Rathenau, *Z.P.*, **87**, 32. (1933)†.

Water vapour has a fairly sharp cut-off at 1800 Å. There is a strong banded region of absorption 1780 to 1610 Å., and another region of strong absorption between 1300 and 1400 Å.

H₂O (*contd.*)**LIQUID WATER**

Liquid water shows infra-red absorption bands at about 7750 and 9850 A., and cuts off the ultra-violet beyond 1800 A.

-OH HYDROXYL

Compounds with an OH- group, *i.e.*, alcohols, all show a strong infra-red absorption band around 9500 A.

Reference. R. M. Badger and S. H. Bauer, *J. Chem. Phys.*, 4, 711. (1936).

H₂O₂

Hydrogen peroxide vapour shows continuous absorption in the ultra-violet. The absorption commences around 3700 A., increases slowly in strength to 3000 A., and then more rapidly to the limit of observations at 2150 A.

Reference. H. C. Urey, L. H. Dawsey and F. O. Rice, *J. Amer. Chem. Soc.*, 51, 1371. (1929).

He₂

Occurrence. In a mildly condensed discharge through helium at a pressure of a few centimetres of mercury.

Appearance. A number of apparently irregularly spaced bands of open rotational structure in the visible and near ultra-violet. Most of the bands are degraded to longer wave-lengths.

Transition. The helium bands can be arranged into a number of series resembling the Rydberg series of line spectra. A treatment of the analysis of the helium spectrum is beyond the scope of this work. The ground state of He₂ is unstable; the excited stable levels fall into two groups, singlets and triplets; the lowest stable levels in order from the ground state are ³Σ_u, ¹Σ_u, ³Π_g, ¹Π_g.

References. A very large number of papers have appeared on the molecular spectrum of helium. The data given below are based on the following early papers:—

W. E. Curtis, *P.R.S.*, 89, 146. (1913)†.

A. Fowler, *P.R.S.*, 91, 208. (1915).

W. E. Curtis, *P.R.S.*, 101, 38 (1922)†; 103, 315. (1923).

W. E. Curtis and R. C. Long, *P.R.S.*, 108, 513. (1925).

The following appear to be the most prominent heads which are degraded to the red; the intensities are our estimates from the published spectrograms:—

λ	I	λ	I	λ	I	λ	I
6398.7	10	4648.5	10	3989.1	5	3462.4	1
6310	3	4625.6	10	3777	4	3356.4	4
5862.1	6	4545.8	5	3676.5	7	3348.0	3
5133.2	2	4157.8	4	3665.0	5	3206.4	2
5108.2	1	4002.3	4	3634	3	3200.6	2
5056.1	3						

Degraded to the violet:—

λ5733.0 9

In addition to the above well-marked heads there is a complex region of strong band structure λ6250–5750 (there may appear to be a head at 5950 under low dispersion) and another from 4500–4400 A. with a head near 4393 when seen under low dispersion. There is also band structure from 4050–3900 A.

HfO

Occurrence. In arc containing hafnium salts.

Appearance. Degraded to the red. Long sequences.

References. W. F. Meggers, *Bur. Stand. J. Res.* **1**, 151. (1928)†.

A. S. King, *Astrophys J.*, **70**, 105. (1929).

No analysis of the bands appears to have been published. The following measurements of the outstanding heads of the groups of bands (presumably heads of sequences) are by King; the intensities, where given, are by Meggers.

λ	I	λ	I	λ	I
5698.0	10	4118.9		3840.0	
5074.7	20	4101.2	20	3654.3	5
4252.1	25	3970.1	10	3327.8	
				3236.1	

Hg₂

Numerous papers have appeared on the emission, absorption and fluorescence bands and continua attributed to Hg₂. Good photographs of these have been published by Rayleigh.

References. Lord Rayleigh, *P.R.S.*, **116**, 702. (1927)†.

P.R.S., **119**, 349. (1928)†.

J. M. Walter and S. Barratt, *P.R.S.*, **122**, 201. (1929).

T. Mrozowska, *Acta. Physica Polonica*, **2**, 81. (1933).

J. Okubo and E. Matuyama, *Tohoku Union Sci. Reports*, **22**, 383. (1933)†.

 λ 2345 TO SHORTER WAVE-LENGTHS

Strong continuum commencing at about 2345 A. and fading out to shorter wave-lengths with superposed diffuse bands observed in emission, absorption and fluorescence.

Maxima of bands :—

λ	I
2342	10
2337	5
2333	1
2330	0

 λ 2540 TO RED

Strong continuum stretching from near the strong line λ 2537 to the red with superposed diffuse bands.

In emission and fluorescence bands are observed 2659–3097 A.

In absorption the superposed bands are clearest 2613–2943 A.

 λ 3350

Broad continuum with maximum at 3350 A. observed in fluorescence.

 $\lambda\lambda$ 3650–4047 and $\lambda\lambda$ 4078–4340

Emission bands have been observed in this region by Okubo and Matuyama.

 λ 4850

Broad continuum with maximum at 4850 A. observed in fluorescence.

Hg₂⁺

Occurrence. Mercury vapour in discharge tubes, especially with Tesla coil excitation.

Appearance. Diffuse bands around 2480 Å. degraded to red.

With large dispersion each band is seen to be a sequence.

Reference. L. G. Winans, *P.R.*, **42**, 800. (1932)†.

Bands as observed by Winans :—

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
2525.4	3		2489.5	4	0, 2	2464	3	2, 0
2518.0	3		2482	5	0, 1	2458.0	3	3, 0
2509.4	2		2476.1	10	0, 0	2449.5	1	
2495.6	3	0, 3	2469.5	5	1, 0			

HgBr

Three systems B, C and D have been observed with HgBr₂ vapour in low-pressure discharge tubes and also in fluorescence of HgBr₂. In absorption, above 1000° C., only the strongest bands of system C, have been observed.

References. J. Lohmeyer, *Z. wiss. Photogr.*, **4**, 367. (1906).

K. Wieland, *Helv. Phys. Acta.*, **2**, 46. (1929)†.

A. Terenin, *Z.P.*, **44**, 713. (1927).

K. Wieland, *Z.P.*, **77**, 157. (1932)†.

K. Wieland, *Helv. Phys. Acta.*, **12**, 295 (1939) and **19**, 408. (1946).

H. G. Howell, *P.R.S.*, **182**, 95. (1943).

SYSTEM B, λλ5080–3200

Appearance. Complex system of line-like bands on a continuum with intensity maximum at about 5010 Å.

Transition. ²Σ → ²Σ, ground state.

Strongest bands measured from end to end or at centre of the "lines" (unpublished data from Wieland, see also Lohmeyer) :—

5076–71–66, 5056–48, 5042–34, 5024–22–20, 5009–05–02, 4999–95, 4988–84, 4976–72–69, 4959–55–52, 4940, 4878, 4865–62, 4848, 4834, 4820, 4775, 4761, 4747, 4734, 4719, 4705, 4691, 4678, 4666–62, 4652–50, 4637, 4626–22.

The same system, excited in the presence of an inert gas in large excess, shows a simple vibrational structure of bands degraded to the red (Wieland, 1939).

Prominent heads (unpublished data from Wieland) :—

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
5036.1	8	3, 26	4951.1	9	0, 20*	4879.1	7	0, 18
5017.7	10	0, 22*	4945.2	8	0, 20	4850.9	7	0, 17*
5010.1	9	0, 22	4918.0	8	0, 19*	4845.5	6	0, 17
4983.7	9	0, 21*	4912.4	7	0, 19	4817.9	7	1, 17*
4977.2	8	0, 21	4884.6	8	0, 18*	4784.5	6	1, 16*

* HgBr⁷⁹, all other heads HgBr⁸¹.

SYSTEM C, λλ2940–2700

Appearance. Narrow groups of bands degraded to shorter wave-lengths.

Transition. Probably ²Π_{1/2} → ²Σ, ground state.

Prominent heads of groups (Wieland, 1929) :—

2914.3 (3), 2906.5 (6), 2898.9 (7), 2891.0 (10), 2883.7 (8), 2875.5 (10), 2868.2 (6), 2861.3 (4), 2853.2 (8), 2846.8 (6), 2840.1 (4).

HgBr (*contd.*)SYSTEM D, $\lambda\lambda 2665-2471$

Transition. Probably ${}^2\Pi_{3/2} \rightarrow {}^2\Sigma$, ground state.

Degraded to shorter wave-lengths. Heads of strong sequences :—

λ	I	Sequence	λ	I	Sequence
2627.8	4	0, 3	2575.1	7	1, 0
2615.3	7	0, 2	2560.2	6	2, 0
2602.7	8	0, 1	2545.5	5	3, 0
2590.2	6	0, 0	2531.5	3	4, 0

HgBr₂

All emission bands previously ascribed to HgBr₂ by Wieland are now ascribed to HgBr. In absorption several continua in the far ultra-violet have been observed by Wieland, and a well-developed system at 1862–1813 Å. of bands degraded to the red has been analysed by Wehrli.

References. K. Wieland, *Z.P.*, **76**, 801 (1932) and **77**, 157. (1932).

M. Wehrli, *Helv. Phys. Acta.*, **11**, 339. (1938)†.

HgCl

Three systems, B, C and D, have been observed in low-pressure discharge tubes. System B has also been observed in fluorescence of HgCl₂ and in chemiluminescence. In absorption only the strongest bands of system C have been observed above 1000° C.

References. J. Lohmeyer, *Z. Wiss. Photogr.*, **4**, 367. (1906).

H. Fränz and H. Kallman, *Z.P.*, **34**, 924. (1925).

A. Terenin, *Z.P.*, **44**, 713. (1927).

K. Wieland, *Helv. Phys. Acta.*, **2**, 46. (1929)†.

K. Wieland, *Z.P.*, **77**, 157. (1932).

K. Wieland, *Helv. Phys. Acta.*, **10**, 323. (1937).

S. D. Cornell, *P.R.*, **54**, 341. (1938)†.

K. Wieland, *Helv. Phys. Acta.*, **14**, 420. (1941)†.

H. G. Howell, *P.R.S.*, **182**, 95. (1943).

K. Wieland, *Helv. Phys. Acta.*, **19**, 408. (1946).

SYSTEM B, $\lambda\lambda 5700-3000$

Appearance. Complex system of line-like bands on a continuum with pronounced intensity maximum at about 5550 Å. Strongest bands measured from end to end or at the centre of the "lines" (unpublished data of Wieland, see also Lohmeyer) :— 5672–68 (3), 5654 (3), 5646 (4), 5624–20 (7), 5615–10 (8), 5588 (9), 5567–64 (9), 5559–55 (8), 5553 (9), 5540–38 (7), 5532–28 (8), 5518 (6), 5512 (5), 5497 (9), 5485 (7), 5457 (6), 5446 (7), 5424 (8), 5321 (8), 5304–01 (6), 5295 (7), 5272 (8), 5255–52 (8), 5232 (6).

Transition. ${}^2\Sigma \rightarrow {}^2\Sigma$, ground state.

The same system, with HgCl₂ excited in the presence of an inert gas in large excess, shows a simple vibrational structure of bands degraded to the red.

HgCl (*contd.*)

Prominent heads (Wieland, 1941) :—

λ	I	v', v''	λ	I	v', v''
5635.7	7	2, 25	5270.3	5	0, 17
5576.3	10	0, 22	5217.8	4	1, 17
5517.2	9	0, 21	5208.5	3	0, 16
5455.2	8	0, 20	5157.5	3	1, 16
5393.7	7	0, 19	5146.8	2	0, 15
5332.1	6	0, 18			

SYSTEM C, $\lambda\lambda 2913-2700$ *Transition.* Probably ${}^2\Pi_{1/2} \rightarrow {}^2\Sigma$, ground state.*Appearance.* Narrow groups of bands degraded to shorter wave-lengths. A vibrational analysis given by Cornell is neither in accordance with the chlorine isotope effect nor with the vibrational frequency of the ground state.

Heads of prominent groups (Wieland, 1929) :—

2891.6 (3), 2870.0 (4), 2858 (2), 2812.2 (7), 2805.3 (6), 2790.5 (10), 2783.8 (9), 2742.1 (5), 2740.8 (8), 2721.3 (3), 2719.5 (6).

SYSTEM D, $\lambda\lambda 2637-2380$ *Transition.* Probably ${}^2\Pi_{3/2} \rightarrow {}^2\Sigma$, ground state.*Appearance.* Bands degraded to shorter wave-lengths.

Heads of strong sequences (Wieland, 1929) :—

λ	I	Sequence	λ	I	Sequence
2609.1	2	0, 5	2516.5	7	0, 0
2590.5	3	0, 4	2495.4	7	1, 0
2572.0	4	0, 3	2474.6	5	2, 0
2553.4	6	0, 2	2454.6	3	3, 0
2535.0	7	0, 1	2435.1	1	4, 0

HgCl₂Emission bands previously ascribed to HgCl₂ are now ascribed to HgCl. In absorption several continuous regions have been observed in the far ultra-violet by Wieland and a well-developed band system at $\lambda\lambda 1731-1671$, degraded to the red, has been analysed by Wehrli.*References.* K. Wieland, *Z.P.*, **76**, 801 (1932) and **77**, 157. (1932).M. Wehrli, *Helv. Phys. Acta.*, **11**, 339. (1938)†.**HgF***Occurrence.* In high-frequency discharge.*Reference.* H. G. Howell, *P.R.S.*, **182**, 95. (1943)†.2330 A. SYSTEM, ${}^2\Pi_{3/2} \rightarrow {}^2\Sigma$.*Appearance.* The marked sequences are degraded to the red, but the rotational structure of most individual bands is degraded to shorter wave-lengths.

The following are the most outstanding of the 43 heads listed by Howell.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
2355.5	5	2, 3 Q	2333.0	7	3, 3 Q	2326.2	8	0, 0 P
2353.3	5	1, 2 Q	2329.7	8	2, 2 Q	2325.6	10	0, 0 Q
2351.9	8	0, 1 Q	2327.3	8	1, 1 Q	2299.7	4	1, 0 Q

HgF (contd.)

2560 A. SYSTEM, ${}^2\Pi_{1/2} \rightarrow {}^2\Sigma$

Appearance. A very strong (0, 0) sequence and less strong (1, 0) and (0, 1) sequences degraded to shorter wave-lengths.

Howell lists the Q heads of 35 bands, but without intensities. The following may be prominent. λ 2624.2 (0, 2), 2591.6 (0, 1), 2590.9 (1, 2), 2559.8 (0, 0), 2559.1 (1, 1), 2527.0 (2, 1).

HgH

- References.* E. Hulthén, *Z.P.*, **32**, 32. (1925).
 E. Hulthén, *Z.P.*, **50**, 319. (1928).
 R. Rydberg, *Z.P.*, **73**, 74. (1931).

4017 A. SYSTEM, ${}^2\Pi \rightarrow {}^2\Sigma$, ground state

A wide-spaced doublet system with bands degraded to the violet, each showing P, Q and R branches. Obtained in discharges through mercury vapour and hydrogen.

P Heads					
v', v''	${}^2\Pi_{3/2} \rightarrow {}^2\Sigma$ λ	I	v', v''	${}^2\Pi_{1/2} \rightarrow {}^2\Sigma$ λ	I
0, 3	4520	2	0, 2	3785	2
0, 2	4394	4	0, 1	3647	3
0, 1	4219	7	0, 0	3500	5
0, 0	4017	10	1, 0	3274	3
1, 1	3900	2	2, 1	3200	2
1, 0	3728	4			

2950 A. SYSTEM, ${}^2\Sigma \rightarrow {}^2\Sigma$

Bands with double P and R branches degraded to the red.

v', v''	Origins	R ₁ Heads	R ₂ Heads
0, 1	3059.8	3057.6	3057.8
0, 0	2951	2949.5	2949.7

2807 A. SYSTEM, ${}^2\Sigma \rightarrow {}^2\Sigma$

Two bands are observed, degraded to the red. Double P and R branches.

v', v''	Origins	R ₁ Head	R ₂ Head
0, 1	2904		
0, 0	2808	2807.3	2807.0

2700 A. SYSTEM, ${}^2\Sigma \rightarrow {}^2\Sigma$

Band with double P and R branches degraded to the red.

v', v''	Origin	R ₂ Head
0, 0	2699	2696

HgH⁺

- Reference.* T. Hori, *Z.P.*, **61**, 481. (1930)†.

2264 A. SYSTEM, ${}^1\Sigma \rightarrow {}^1\Sigma$, ground state

An extensive system of bands degraded to the red, each with a single P and single R branch. Occurs in discharges through hydrogen and mercury vapour where ionisation is favoured, as in hollow cathode.

HgH⁺ (*contd.*)

v', v''	R Heads	I
0, 0	2263.9	10
1, 1	2286.7	5
0, 1	2367.3	9
1, 2	2388.1	8
2, 3	2413.3	3
0, 2	2474.7	4
1, 3	2493.9	7

HgI

Nine systems have been observed with HgI₂ in discharge tubes, including high-frequency discharges. The most prominent of the systems, B, C and D, which involve the ground state, have also been observed in fluorescence of HgI₂. The blue-violet system B can also be excited with active nitrogen. In absorption, above 1000° C., the strongest bands of system C and, very faintly, those of system B have been observed.

- References.* J. Lohmeyer, *Z. wiss. Photogr.*, **4**, 367. (1906).
 R. S. Mulliken, *P.R.*, **26**, 1. (1925).
 A. Terenin, *Z.P.*, **44**, 713. (1927).
 K. Wieland, *Helv. Phys. Acta.*, **2**, 46. (1929)†.
 N. Prileshajewa, *Phys. Z. Sow. Union*, **1**, 189. (1932).
 K. Wieland, *Z.P.*, **76**, 801. (1932)†.
 Duschinsky and P. Pringsheim, *Physica*, **2**, 922. (1935)†.
 T. S. Subbaraya, B. N. Rao and N. A. N. Rao, *Proc. Indian Acad. Sci.*, **5A**, 365. (1937)†.
 H. G. Howell, *P.R.S.*, **182**, 95. (1943).
 K. R. Rao, M. G. Sastry and V. G. Krishnamurti, *Indian J. Phys.*, **18**, 323. (1944).
 K. R. Rao and V. R. Rao, *Indian J. Phys.*, **20**, 148. (1946).
 K. R. Rao and C. R. Sastry, *Curr. Sci.*, **16**, 54. (1947).
 C. Ramasastry and K. R. Rao, *Indian J. Phys.*, **21**, 143. (1947)†.
 C. Ramasastry, *Indian J. Phys.*, **22**, 95. (1948)†.

SYSTEM B, $\lambda\lambda 4520-3600$

Transition. $^2\Sigma \rightarrow ^2\Sigma$, ground state.

Appearance. Complex system of line-like bands standing out from a continuum with pronounced intensity maximum at about 4440 Å.

Prominent bands measured at the centre of the "lines" (unpublished data of Wieland, see also Lohmeyer) :—

4456, 4440, 4429, 4423, 4412, 4392, 4381, 4350, 4340, 4328, 4321, 4310, 4281, 4271, 4262-60, 4251, 4239, 4214, 4204, 4159, 4150, 4139, 4129.

The same system, with HgI₂ excited in the presence of an inert gas in large excess, shows a simple vibrational structure of bands degraded to the red.

Prominent heads (unpublished data of Wieland) :—

λ	I	v', v''	λ	I	v', v''
4488.2	3		4440.2	9	1, 18
4476.1	6	1, 19	4423.3	8	1, 17
4455.4	10	1, 19	4411.6	10	0, 15

HgI (contd.)

λ	I	v', v''	λ	I	v', v''
4391.6	7	1, 15	4277.4	4	3, 11
4373.3	6	1, 14	4257.4	3	4, 11
4355.4	6	1, 13	4238.8	3	4, 10
4316.2	5	2, 12	4219.3	2	5, 10
4295.8	5	3, 12	4200.5	2	5, 9

SYSTEM C, $\lambda\lambda 3095-2850$

Transition. ${}^2\Pi_{1/2} \rightarrow {}^2\Sigma$, ground state.

Appearance. Bands degraded to shorter wave-lengths.

Strongest heads (Wieland, 1932) :—

λ	I	v', v''	λ	I	v', v''
3083.6	3	0, 3	3041.4	5	(2, 3)
3072.4	6	0, 2	3031.8	3	4, 6
3061.8	8	1, 3	3028.0	5	1, 0
3061.0	10	0, 1	3007.4	4	2, 0
3051.5	6	2, 4	2998.5	4	3, 1
3049.5	7	0, 0	2979.0	4	4, 1

SYSTEM D, $\lambda\lambda 2850-2650$

Transition. ${}^2\Pi_{3/2} \rightarrow {}^2\Sigma$, ground state.

Appearance. Bands degraded to shorter wave-lengths somewhat obscured by overlapping bands of systems C and E.

The (0, 0) band lies at 2754.4 Å. (Rao, Sastry and Krishnamurti, 1944).

SYSTEM E, $\lambda\lambda 2700-2550$

Appearance. A number of broad bands (Wieland, 1932).

The region $\lambda\lambda 2530-2320$ was divided into three systems by Rao and Rao (1946) and these systems were later studied in greater detail by Ramasastry, (1948).

SYSTEM F₁, $\lambda\lambda 2534-2450$

Ramasastry has measured 54 heads of this system of bands degraded to the red. Strongest bands :—

2487.6 (5), 2493.1 (5), 2500.6 (5), 2506.1 (6), 2509.9 (5), 2532.7 (6), 2533.8 (6).

SYSTEM F₂, $\lambda\lambda 2437-2381$

Rao and Rao measured 34 closely-spaced bands degraded to the red.

SYSTEM F₃, $\lambda\lambda 2350-2260$

Ramasastry has measured 84 heads degraded to the red. Strongest bands :—

2321.7 (6), 2322.0 (5), 2325.6 (6), 2330.1 (6), 2331.1 (6), 2332.0 (5), 2334.8 (6), 2335.7 (5), 2336.9 (6), 2540.7 (10).

SYSTEM G, $\lambda\lambda 2230-2165$

Ramasastry and Rao (1947) have measured 59 bands degraded to the red. Strongest heads :—

2213.6 (5), 2207.8 (6), 2197.7 (6), 2187.6 (6), 2183.4 (5), 2179.3 (5).

HgI (*contd.*)**SYSTEM H, $\lambda\lambda$ 2170–2110**

Ramasastri and Rao (1947) have measured 22 bands degraded to the red.

Strongest heads :—

2150.4 (5), 2144.3 (5), 2139.0 (6), 2133.7 (5).

HgI₂

All emission bands previously ascribed to HgI₂ are probably due to HgI. In absorption there are several regions of continuum (Wieland) and a system of bands degraded to the red (Wehrli).

References. K. Wieland, *Z.P.*, **76**, 801 (1932) and **77**, 157. (1932).

M. Wehrli, *Helv. Phys. Acta.*, **11**, 339. (1938)†.

HgO ?

Reference. J. M. Walter and S. Barratt, *P.R.S.*, **122**, 201. (1929).

Walter and Barratt record absorption bands $\lambda\lambda$ 2943–2739 using mercury vapour and oxygen. The assignment to HgO is uncertain.

HgS

Reference. P. K. Sen Gupta, *P.R.S.*, **143**, 438. (1933–4).

Continuous absorption in three regions beginning at $\lambda\lambda$ 4450, 3100 and 2250.

I₂

A large number of papers have been published on the spectrum of iodine. The most readily observed system is the well-known visible absorption bands which are responsible for the violet colour of the vapour. All the band systems of iodine are composed of a very large number of close narrow bands, and distinctive features are lacking.

VISIBLE SYSTEM

Occurrence. This system has been studied principally in absorption. Bands have been observed in fluorescence, and Uchida has obtained the system in emission by the heated vapour. There seems to be no obvious reason why the bands should not appear readily in emission in other sources.

Appearance. Degraded to longer wave-lengths. Numerous regularly spaced bands extending from the far red to the absorption limit at about 5000 Å. The system is too extensive to publish wave-lengths, but a spectrogram is shown in Plate 10.

Transition. $O^+ \rightleftharpoons {}^1\Sigma^+$, ground state.

References. R. Mecke, *Ann. Physik.*, **71**, 104. (1923).

F. W. Loomis, *P.R.*, **29**, 112. (1927).

Y. Uchida, *Inst. Phys. Chem. Res. Tokyo Sci. Papers*, No. 651, p. 71. (1936)†.

ULTRA-VIOLET SYSTEMS

Occurrence. Bands beyond 2150 Å. appear readily in absorption, and by heating the vapour and using greater thicknesses absorption bands have been observed to 3400 Å. Bands are also observed in fluorescence.

I₂ (*contd.*)

- References.* P. Pringsheim and B. Rosen, *Z.P.*, **50**, 1. (1928).
 M. Kimura and M. Miyanishi, *Inst. Phys. Chem. Res. Tokyo Sci. Papers*, **10**, 33. (1929)†.
 E. Hirschlaff, *Z.P.*, **75**, 325. (1932).
 W. E. Curtis and S. F. Evans, *P.R.S.*, **141**, 603. (1933).
 D. T. Warren, *P.R.*, **47**, 1. (1935).

INFRA-RED

Absorption bands from 8300 Å. to 9300 Å. have been observed by Brown.

Reference. W. G. Brown, *P.R.*, **38**, 1187. (1931).

EMISSION BANDS

Reference. A. E. Elliott, *P.R.S.*, **174**, 273. (1940)†.

Elliott describes the fluorescence excited in iodine vapour in nitrogen at atmospheric pressure by an aluminium spark. He obtains:—

(1) A system of bands $\lambda\lambda 2727$ – 2514 degraded to longer wave-lengths. About 60 bands are observed.

(2) The "continuum" $\lambda 3425$. Numerous close bands, degraded to the red, close up at $\lambda 3436$ giving the appearance of a broad head degraded to the violet. About 70 bands appear in the range $\lambda\lambda 3450$ – 3040 . This also occurs in flames.

(3) The "continuum" $\lambda 4300$. Numerous bands degraded to the red with a structure, somewhat similar to that of the last system, at $\lambda 4321$. Some 45 bands in range $\lambda\lambda 4321$ – 4041 .

(4) A group of bands resembling the last, but weaker, at $\lambda 4630$. The bands degrade to the violet unlike all others. In the range $\lambda\lambda 4630$ – 4440 some 19 bands are observed the most intense at $\lambda 4596$.

- References.* P. Venkateswarlu, *Proc. Indian Acad. Sci.*, **A24**, 373. (1946).
 P. Venkateswarlu, *Proc. Indian Acad. Sci.*, **A24**, 480. (1946).
 P. Venkateswarlu, *Proc. Indian Acad. Sci.*, **A25**, 119. (1947).
 P. Venkateswarlu, *Proc. Indian Acad. Sci.*, **A25**, 133. (1947).

These papers give observations on:—

The Cordes bands $\lambda\lambda 1950$ – 1500 .

The emission excited by a high-frequency discharge in iodine vapour. Discrete bands degraded to the red in the region $\lambda\lambda 6700$ – 5000 are found to be identical with well-known absorption bands. Between $\lambda 4800$ and $\lambda 2400$ groups of diffuse bands appear. Intensity maxima are measured in the two ranges $\lambda\lambda 4154$ – 3978 and $\lambda\lambda 2712$ – 2687 .

IBr

Occurrence. In absorption.

Appearance. Degraded to longer wave-lengths. Waves of closely-spaced bands extending from the green to the red have been arranged into two systems, and there is a third system in the near infra-red. Cordes gives a long table of wave-lengths of the visible bands, but no intensities are available.

- References.* R. M. Badger and D. M. Yost, *P.R.*, **37**, 1548. (1931).
 H. Cordes, *Z.P.*, **74**, 34. (1932).
 W. G. Brown, *P.R.*, **42**, 355. (1932).

ICI

Occurrence. In absorption.

Appearance. Degraded to the red. An extensive system of closely-spaced bands from the yellow green to the near infra-red. The strongest bands apparently form two long progressions in the orange to red. Under large dispersion the heads are not very obvious. Wave-lengths and some photographs have been published by Curtis and Patkowski.

References. O. Darbyshire, *P.R.*, **40**, 366. (1932).

G. E. Gibson and H. C. Ramsperger, *P.R.*, **30**, 598. (1927).

W. E. Curtis and J. Patkowski, *Phil. Trans. Roy. Soc.*, **232**, 395. (1934)†.

IO**METHYL IODIDE FLAME BANDS**

Occurrence. In flames containing iodine, or methyl iodide. They are emitted most strongly in the region just above the inner cone.

Appearance. Degraded to the red. A fairly simple system.

References. W. M. Vaidya, *Indian Acad. Sci. Proc.*, **6A**, 122. (1937)†.

E. H. Coleman, A. G. Gaydon and W. M. Vaidya, *Nature, Lond.*, **162**, 108 (1948)†.

The bands were originally divided into two systems, but are now known to form a single system. The following are the strongest heads :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
6231.5	4	3, 11	5495	9	0, 5	4693.5	9	1, 1
6193	4	2, 10	5307.5	10	0, 4	4586.7	10	2, 1
5976	7	2, 9	5208.8	5	2, 5	4487.7	10	3, 1
5939	6	1, 8	5131.0	9	0, 3	4448.7	7	2, 0
5900	5	0, 7	5002.3	6	1, 3	4396.7	6 <i>d</i>	4, 1
5730	8	1, 7	4963.6	6	0, 2	4355.9	9	3, 0
5692	7	0, 6	4844.5	10	1, 2	4286.2	7 <i>d</i>	4, 0
5533	7	1, 6	4731.2	7	2, 2	4189.0	5 <i>d</i>	5, 0

d = diffuse.

In₂

Occurrence. In absorption and fluorescence of indium vapour.

Reference. R. Wajnkranc, *Z.P.*, **104**, 122. (1936–7).

The following are the chief features of the absorption spectrum :—

Diffuse broad bands maxima $\lambda\lambda$ 3818, 3734, 3680.

3548–3523 Å. A group of narrow bands degraded to the red.

3259 Å. A group of narrow bands to the red of the In line.

2340 Å. A group of narrow bands on the shorter wave-length side of the In line.

InBr

Three systems have been observed in emission in a high-frequency discharge and in absorption. Also in fluorescence of InBr₂ (W. Wenk).

References. A. Petrikaln and J. Hochberg, *Z.P.*, **86**, 214. (1933)†.

M. Wehrli and E. Miescher, *Helv. Phys. Acta*, **7**, 298. (1934)†.

INDIVIDUAL BAND SYSTEMS

151

InBr (*contd.*)

SYSTEM A, $\lambda\lambda 3852-3641$

Some bands degraded slightly to shorter wave-lengths. Strongest bands :—

λ	I	v', v''
3789.8	4	0, 1
3758.5	8	0, 0
3727.2	4	1, 0

SYSTEM B, $\lambda\lambda 3726-3568$

Some bands degraded slightly to red. Strongest bands :—

λ	I	v', v''
3681.1	9	1, 2
3651.2	10	0, 0
3596.7	6	3, 1
3595.3	6	2, 0

SYSTEM C, $\lambda\lambda 3083-2852$

Single progression of diffuse bands, 2852 (0, 0), 2896 (0, 1), 2926 (0, 2), 2956 (0, 3), etc.

InBr₂

W. Wenk (*Dissertation, Basel, 1941*) has observed absorption continua at 2555, 2275, 2060 and 1895 A.

InCl

Three systems have been observed in emission in a high-frequency discharge, and also in absorption. Also in fluorescence of InCl₂ (W. Wenk).

References. A. Petrikaln and J. Hochberg, *Z.P.*, **86**, 214. (1933)†.

M. Wehrli and E. Miescher, *Helv. Phys. Acta*, **7**, 298. (1934)†.

E. Miescher and M. Wehrli, *Helv. Phys. Acta*, **6**, 256. (1934).

SYSTEM A, $\lambda\lambda 3640-3471$

Degraded to shorter wave-lengths. Strongest bands :—

λ	I	v', v''	λ	I	v', v''
3599.2	6	0, 0	3554.0	4	2, 1
3596.5	2	1, 1	3514.6	2	2, 0
3556.2	5	1, 0	3513.0	3	3, 1

SYSTEM B

Degraded to shorter wave-lengths. Q heads of strongest bands,

λ	I	v', v''
3499.0	8	0, 0
3458.5	5	1, 0
3456.3	4	2, 1
3419.3	3	2, 0

SYSTEM C

Degraded to the red. Strongest bands at $\lambda\lambda 2672.1$ (0, 0), 2694.7 (0, 1), 2717.5 (0, 2), 2740.6 (0, 3) and $\lambda\lambda 2661.3$ (1, 0), 2683.7 (1, 1) in absorption only.

InCl₂

W. Wenk (*Dissertation, Basel*, 1941) has observed absorption continua at 2390, 2160, 1920 and 1818 Å.

InH

References. B. Grundström, *Z.P.*, **113**, 721. (1939).
B. Grundström, *Nature, Lond.*, **141**, 555. (1938).

Occurrence. Arc in hydrogen between carbon and indium electrodes.

¹Σ → ¹Σ SYSTEM

Bands degraded to the red with single P and R branches. Band origins :—

λ	v', v''	λ	v', v''
7044	3, 4	6190.9	1, 1
6861.1	2, 3	6148.5	0, 0
6459.4	3, 3	5785.8	2, 1
6286.9	2, 3	5688.6	1, 0

¹Π → ¹Σ SYSTEM

Bands degraded to the violet with single P, Q and R branches. The final level is the same as for the above system. Band origins :—

λ	v', v''	λ	v', v''
6458.5	0, 1	5963.3	1, 1
6071.0	2, 2	5913.8	0, 0

InI

Two overlapping systems λλ4293–3948 with (0, 0) bands at 4098.5 and 3993.4 Å. have been observed in a high-frequency discharge and in absorption. Also in fluorescence of InI₂ (W. Wenk). There is also a continuum with maximum at about 3173 Å.

Reference. M. Wehrli and E. Miescher, *Helv. Phys. Acta*, **7**, 298. (1934)†.

InI₂

W. Wenk (*Dissertation, Basel*, 1941) has observed absorption continua at 2640, 2465 and 2100 Å.

InO

Bands 4500–4100 Å. have been observed in an arc ; the strong bands are stated to be degraded to the red ; no wave-lengths are available.

Reference. M. L. Guernsey, *P.R.*, **46**, 114. (1934).

K₂

Strong band systems attributed to K₂ have been observed in the far red, the near red and the blue, and weaker systems are reported in the ultra-violet.

FAR RED SYSTEM

Occurrence. In absorption.

Appearance. Numerous bands in the region λλ8840–7728 degraded to longer wave-lengths.

K₂ (*contd.*)

Transition. B $^1\Sigma \leftarrow$ A $^1\Sigma$, ground state.

References. J. C. McLennan and D. S. Ainslie, *P.R.S.*, **103**, 304. (1923)†.

W. O. Crane and A. Christy, *P.R.*, **36**, 421. (1930).

Crane and Christy record a long list of heads, but no intensities. The following wave-lengths may assist the identification :—8702.0 (0, 2), 8634.4 (0, 1), 8566.3 (0, 0), 8515.7 (1, 0), 8468.2 (2, 0). McLennan and Ainslie record maxima at $\lambda\lambda$ 8602, 8547, 8492, 8447, 8407, 8375, 8309, 8266 and 8213.

NEAR RED SYSTEM

Occurrence. In absorption, in fluorescence and in magnetic rotation.

Appearance. Numerous bands in the region $\lambda\lambda$ 6922–6280, degraded to the red.

Transition. C $^1\Pi \leftarrow$ A $^1\Sigma$, ground state.

References. W. R. Fredrickson and W. W. Watson, *P.R.*, **30**, 429. (1927).

W. O. Crane and A. Christy, *P.R.*, **36**, 421. (1930).

F. W. Loomis and R. E. Nusbaum, *P.R.*, **39**, 89. (1932).

Strongest heads :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
6629.8	5	1, 4	6473.9	10	1, 0
6622.8	6	0, 3	6443.2	8	2, 0
6583.4	9	0, 2	6413.0	7	3, 0
6544.1	8	0, 1	6383.7	5	4, 0
6512.6	5	1, 1			

BLUE SYSTEM, $\lambda\lambda$ 4510–4220

Occurrence. In absorption.

Appearance. Degraded to the red.

Transition. D $^1\Sigma \leftarrow$ A $^1\Sigma$, ground state.

References. H. Yamamoto, *Jap. J. Phys.*, **5**, 153. (1929).

S. P. Sinha, *Proc. Phys. Soc.*, **60**, 436. (1948).

Strongest heads :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
4460.3	5	0, 6	4367.8	5	2, 2	4320.9	7	3, 0
4442.6	6	0, 5	4361.0	6	1, 1	4310.0	7	4, 0
4425.5	6	0, 4	4355.1	8	0, 0	4299.0	8	5, 0
4407.7	5	0, 3	4349.7	6	2, 1	4294.5	5	7, 1
4390.2	5	0, 2	4343.5	10	1, 0	4288.4	8	6, 0
4378.4	6	1, 2	4338.1	5	3, 1	4277.6	6	7, 0
4372.9	7	0, 1	4332.3	7	2, 0	4273.6	6	9, 1

ULTRA-VIOLET SYSTEM, $\lambda\lambda$ 4165–3940

Occurrence. In absorption.

Appearance. Degraded to the red.

References. H. Yoshinaga, *Proc. Phys. Math. Soc. Japan*, **19**, 847. (1937).

S. P. Sinha, *Proc. Phys. Soc.*, **60**, 436. (1948).

Strongest heads :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
4127.6	5	1, 5	4122.7	6	0, 4	4112.8	8	1, 4
4123.6	5	3, 6	4119.8	5	5, 7	4108.6	6	3, 5

K₂ (*contd.*)

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
4107.3	7	0, 3	4082.7	10	1, 2	4016.3	5	5, 0
4103.0	6	2, 4	4078.2	6	3, 3	4008.0	5	6, 0
4099.1	5	4, 5	4067.0	8	1, 1	3999.6	5	7, 0
4097.4	7	1, 3	4057.9	5	2, 1	3991.6	5	8, 0
4092.3	8	0, 2	4033.5	6	3, 0	3984.7	5	11, 1
4087.5	6	2, 3	4024.9	6	4, 0	3978.0	5	12, 1

OTHER BANDS

Bands belonging to weaker systems extend to about $\lambda 2900$.

References. H. Yoshinaga, *Proc. Phys. Math. Soc. Japan*, **19**, 847. (1937).

S. P. Sinha, *Proc. Phys. Soc.*, **60**, 436. (1948).

B. K. Chakraborti (*Indian J. Phys.*, **10**, 155 (1936)) has reported absorption bands associated with each doublet of the principal series; these bands only appear at high temperatures.

KBr

The heated vapour shows strong continuous absorption in the middle ultra-violet, merging into diffuse banded absorption in the near ultra-violet.

Reference. K. Sommermeyer, *Z.P.*, **56**, 548. (1929).

KCd

Diffuse bands, degraded to the violet, observed in absorption by Barratt (see CsCd). Heads $\lambda\lambda 4191, 4172$.

KCs

Reference. J. M. Walter and S. Barratt, *P.R.S.*, **119**, 257. (1928).

Diffuse absorption band at $\lambda 5387$.

KH

References. G. M. Almy and C. D. Hause, *P.R.*, **42**, 242. (1932).

T. Hori, *Mem. Ryojun Coll. Eng.*, **6**, 1, 33. (1933).

G. Almy and A. Beiler, *P.R.*, **61**, 476. (1942).

5100 A. SYSTEM, $^1\Sigma \rightarrow ^1\Sigma$, GROUND STATE

System of the many-lined type with weak R-heads degraded to the red. The system is readily obtained in absorption from a mixture of hydrogen and potassium vapour and in emission from a potassium arc in hydrogen or from discharges through a mixture of hydrogen and potassium vapour.

Origins of strongest bands :—

v', v''	λ_0	v', v''	λ_0
2, 2	5613.4	5, 0	4870.2
3, 2	5528.7	6, 0	4802.8
4, 2	5444.7	7, 0	4736.7
5, 2	5362.3	8, 0	4672.2
3, 1	5259.0	9, 0	4608.9
4, 1	5183.3	10, 0	4547.5
5, 1	5108.3	11, 0	4487.7
6, 1	5034.0	12, 0	4429.7
7, 1	4960.6	13, 0	4373.5

KHg

Diffuse bands, degraded to the violet, observed in absorption by Barratt (see CsCd). Heads $\lambda\lambda 6188, 6150, 4113$ and 3988 .

KI

The heated vapour shows strong continuous absorption in the near ultra-violet, merging into diffuse banded absorption in the violet.

Reference. K. Sommermeyer, *Z.P.*, **56**, 548. (1929)†.

KRb

Reference. J. M. Walter and S. Barratt, *P.R.S.*, **119**, 257. (1928).

Diffuse absorption band at $\lambda 4959$.

KZn

Diffuse band, degraded to the violet, observed in absorption by Barratt (see CsCd). Head $\lambda 4147$.

LaO

Strong systems attributed to lanthanum oxide have been observed in the red, the yellow, and the blue, and there is also a weaker system in the near ultra-violet.

Occurrence. In arcs fed with lanthanum salts.

References. W. F. Meggers and J. A. Wheeler, *Bur. Stand. J. Res.*, **6**, 239. (1931)†.

W. Jevons, *Proc. Phys. Soc.*, **41**, 520. (1929).

F. A. Jenkins and A. Harvey, *P.R.*, **39**, 922. (1931).

RED SYSTEM, $\lambda\lambda 6867-9729$

Appearance. Degraded to longer wave-lengths. Marked sequences.

Transition. $A \ ^2\Pi \rightarrow X \ ^2\Sigma$, ground state.

The following are the strongest heads at the beginning of the main sequences. Measurements are by Meggers and Wheeler; intensities have been reduced to a scale of 10. The two sub-bands due to the doubling of the $^2\Pi$ state are denoted by i and ii.

λ	I	v', v''	λ	I	v', v''
6994.5	1	1, 0 i R	7877.2	6	0, 0 ii R
7011.2	2	1, 0 i Q	7910.5	8	0, 0 ii Q
7023.6	1	2, 1 i R	7912.3	3	1, 1 ii R
7040.8	2	2, 1 i Q	7944.9	6	1, 1 ii Q
7054.8	1	3, 2 i R	7947.9	2	2, 2 ii R
7070.8	2	3, 2 i Q	7979.7	5	2, 2 ii Q
7379.8	8	0, 0 i R	8406.0	1	0, 1 ii R
7403.5	10	0, 0 i Q	8443.3	2	1, 2 ii R
7411.3	5	1, 1 i R	8453.5	3	0, 1 ii Q
7434.3	6	1, 1 i Q	8481.0	1	2, 3 ii R
7442.9	4	2, 2 i R	8489.9	3	1, 2 ii Q
7465.2	5	2, 2 i Q	8526.6	3	2, 3 ii Q

LaO (*contd.*)YELLOW SYSTEM, $\lambda\lambda 6450-5015$

Appearance. Degraded to the red. Marked sequences. The bands show close double heads (R_1 and R_2) separation about 2.5 Å.

Transition. $B \ ^2\Sigma \rightarrow X \ ^2\Sigma$, ground state.

The following measurements of the first of the close double heads are by Jevons. Intensities, where given, are based on Meggers and Wheeler's reduced to a scale of 10. Only the prominent heads are given.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
5178.3		2, 0	5599.9	10	0, 0	5920.7	4	2, 3
5202.7		3, 1	5626.0	5	1, 1	6157.4	0	0, 2
5380.4	1	1, 0	5652.3	3	2, 2	6185.7	1	1, 3
5405.6	2	2, 1	5866.3	3	0, 1	6214.1	1	2, 4
5430.9	2	3, 2	5893.4	4	1, 2	6242.6	2	3, 5

BLUE SYSTEM, $\lambda\lambda 4348-4622$

Appearance. Degraded to the red. Two strong and some weaker sequences of very close (separation 0.1 Å.) double-headed bands.

Transition. $C \ ^2\Pi \rightarrow X \ ^2\Sigma$, ground state.

The following are the bands forming the heads of the sequences. Measurements compiled from Jevons, and Meggers and Wheeler. Intensities, where given, are based on those given by Meggers and Wheeler reduced to scale of 10. The two sub-bands due to the $^2\Pi$ level are denoted by i and ii.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
4348.2			4379.6	4	2, 2 i	4433.0	6	3, 3 ii
4352.2			4383.4	3	3, 3 i	4580.7	1	0, 1 ii
4356.3			4418.1	10	0, 0 ii	4585.0	1	1, 2 ii
4371.9	8	0, 0 i	4423.1	8	1, 1 ii	4589.4	1	2, 3 ii
4375.7	6	1, 1 i	4428.0	6	2, 2 ii	4593.8	1	3, 4 ii

ULTRA-VIOLET SYSTEM, $\lambda\lambda 3457-3709$

Appearance. Degraded to shorter wave-lengths.

Transition. Uncertain. The final state is probably $X \ ^2\Sigma$.

The following are the strong bands as listed by Jevons :—

λ	I	λ	I
3709.6	3	3604.6	6
3614.9	6	3566.2	5
3611.5	6	3560.9	4
3608.1	6	3556.3	3

Li₂

Occurrence. Two systems have been observed, in the red and in the blue-green, in absorption, magnetic rotation, and in fluorescence. A third system in the ultra-violet region has been observed in absorption.

Li₂ (*contd.*)RED SYSTEM, $\lambda\lambda 7700-6550$ *Appearance.* Degraded to longer wave-lengths.*Transition.* ${}^1\Sigma \rightarrow {}^1\Sigma$, ground state.*Reference.* K. Wurm, *Z.P.*, **59**, 35. (1930).

Strong bands :—

λ	<i>I</i>	v', v''
7690·3	8	0, 2
7309·8	8	0, 1
7177·4	8	1, 1
7003·7	8	1, 0
6883·9	10	2, 0
6768·7	8	3, 0
6659·3	8	4, 0

BLUE-GREEN SYSTEM, $\lambda\lambda 5600-4500$ *Appearance.* Degraded to the red.*Transition.* ${}^1\Pi \rightarrow {}^1\Sigma$, ground state.*Reference.* A. McKellar, *P.R.*, **44**, 155. (1933).

Strongest bands :—

λ	v', v''
4985·6	0, 1
4901·0	0, 0
4838·3	1, 0
4778·6	2, 0

ULTRA-VIOLET SYSTEM, $\lambda\lambda 3500-3100$ *Reference.* S. P. Sinha, *Proc. Phys. Soc.*, **60**, 443. (1948).*Appearance.* Degraded to the red.*Transition.* Probably ${}^1\Sigma \rightarrow {}^1\Sigma$, ground state.

Strongest bands :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3431·2	4	0, 4	3277·6	6	0, 0
3404·4	4	1, 4	3253·1	10	1, 0
3392·1	6	0, 3	3206·9	6	3, 0
3353·6	10	0, 2	3184·2	6	4, 0
3315·6	9	0, 1	3162·0	5	5, 0

LiCs

Bands, degraded to the red, have been observed in absorption by a mixture of lithium and caesium vapours.

References. J. M. Walter and S. Barratt, *P.R.S.*, **119**, 257. (1928).W. Weizel and M. Kulp, *Ann. Physik.*, **4**, 971. (1930).Strongest bands : $\lambda\lambda 6255, 6217, 6180, 6146$ and 6116 .**LiH***References.* G. Nakamura, *Z.P.*, **59**, 218. (1930).F. H. Crawford and T. Jorgensen, *P.R.*, **47**, 932. (1935).

LiH (*contd.*)**3900 A. SYSTEM, $^1\Sigma \rightarrow ^1\Sigma$, ground state**

This system presents a many-lined appearance which recalls the spectrum of molecular hydrogen. Weak R heads degraded to the red are formed near the origins, but are not obvious on casual inspection. The system is readily obtained in absorption from a mixture of hydrogen and lithium vapour and in emission from a lithium arc in hydrogen or a discharge through a mixture of hydrogen and lithium vapour.

Origins of the strongest bands :—

v', v''	λ_0	v', v''	λ_0
0, 2	4297.5	3, 0	3720.2
1, 2	4245.2	4, 0	3672.0
2, 2	4189.5	5, 0	3623.3
1, 1	4020.7	6, 0	3574.6
2, 1	3970.7	7, 0	3526.4
3, 1	3918.5	8, 0	3478.8
2, 0	3767.2	9, 0	3432.2

TRIPLET SYSTEM ?

Crawford and Jorgensen note a close grouping of lines in the far red which they suggest belong to another system.

LiK

References. See LiCs.

Absorption bands degraded to the red. Strongest bands $\lambda\lambda 5838.7, 5769.3, 5724.0, 5700.0, 5658.0$ and 5620.0 .

LiRb

References. See LiCs.

Absorption bands degraded to the red. Strongest bands $\lambda\lambda 5815.5, 5778.0, 5743.0$ and 5712.5 .

LuO

Occurrence. Lutecium salts in arc.

Appearance. Degraded to the red. Head of strong (0, 0) sequence at $\lambda 4661.7$; a few weaker bands of the (0, 1) and (1, 0) sequences have been observed.

Reference. W. W. Watson and W. F. Meggers, *Bur. Stand. J. Res.*, **20**, 125. (1938)†.

The following are the strongest heads at the beginning of the (0, 0) sequence :—

λ	I	v', v''
4661.7	10	0, 0
4672.3	9	1, 1
4684.2	8	2, 2
4695.5	6	3, 3
4708.0	4	4, 4

Mg₂

Reference. H. Hamada, *Phil. Mag.*, **12**, 50. (1931)†.

Hamada has studied the emission by magnesium in a hollow cathode. The magnesium lines, especially $\lambda 2852$, are broadened, and the spectrum shows patches of continuum and flutings which are attributed to incipient formation of Mg₂ molecules.

MgBr

Occurrence. In absorption, in flames and probably in arcs.

Appearance. Degraded to the violet. Marked sequences of close bands.

Transition. Probably ${}^2\Pi \rightarrow {}^2\Sigma$, ground state.

Reference. F. Morgan, *P.R.*, **50**, 603. (1936).

λ	
3936.8	P ₁ head of weak (0, 1) band and sequence.
3880.5	P ₁ head of strong (0, 0) band and sequence.
3877.8	P ₁ head of (1, 1) band.
3864.1	P ₂ head of strong (0, 0) band and sequence.
3823.4	P ₁ head of rather weak (1, 0) band and sequence.

MgCl

Occurrence. In absorption, in flames and arcs.

Appearance. Degraded to violet. Marked sequences of close bands.

Transition. Probably ${}^2\Pi \rightarrow {}^2\Sigma$, ground state.

Reference. F. Morgan, *P.R.*, **50**, 603. (1936).

λ	
3845.2	P ₁ head of (0, 1) band and sequence.
3778.9	P ₁ head of strong (0, 0) band and sequence.
3775.3	P ₁ head of (1, 1) band.
3770.2	P ₂ head of (0, 0) band and sequence.
3711.0	P ₁ head of (1, 0) band and sequence.

MgF

There are three systems due to MgF in the ultra-violet, the strongest $\lambda\lambda 3686-3468$, and weaker systems $\lambda\lambda 2742-2649$ and $\lambda\lambda 2249-2387$.

STRONG SYSTEM, $\lambda\lambda 3686-3468$

Occurrence. Carbon arc fed with MgF₂, and also in absorption.

Appearance. Degraded to shorter wave-lengths. Well-marked double-headed sequences.

Transition. A ${}^2\Pi \rightarrow {}^2\Sigma$, ground state.

References. S. Datta, *P.R.S.*, **99**, 436. (1921)†.

C. A. Fowler, *P.R.*, **59**, 645. (1941)†.

Outstanding features :—

λ	<i>I</i>	
3685.8	5	Head of (0, 1) sequence.
3594.2	10	P ₁ head of (0, 0) band and sequence.
3592.8		P ₂ head of (0, 0) band.
3588.4		Q ₂ head of (0, 0) band.
3503.4	4	P ₁ head of (1, 0) band and sequence.

MgF (*contd.*)SYSTEM $\lambda\lambda 2742-2649$

Occurrence. Carbon arc fed with MgF_2 , and also in absorption.

Appearance. Degraded to shorter wave-lengths. Well-marked sequences of single-headed bands.

Transition. B $^2\Sigma \rightarrow ^2\Sigma$, ground state.

Reference. W. Jevons, *P.R.S.*, **122**, 211. (1929)†.

Strongest bands :—

λ	<i>I</i>	v', v''
2741.6	2	0, 1
2689.3	5	0, 0
2686.5	4	1, 1
2636.5	3	1, 0

SYSTEM $\lambda\lambda 2249-2387$

Occurrence. In absorption.

Appearance. Degraded to shorter wave-lengths. Well-marked sequences.

Transition. C $^2\Sigma \rightarrow ^2\Sigma$, ground state.

Reference. C. A. Fowler, *P.R.*, **59**, 645. (1941)†.

Outstanding heads :—

λ	<i>I</i>	v', v''
2387.9	2	0, 1
2347.8	10	0, 0
2342.1	5	1, 1
2303.6	5	1, 0
2298.6	4	2, 1

Absorption bands around 2275 Å. reported by Jenkins and Grinfeld (*P.R.*, **43**, 943 (1933)) are due to AlF.

MgH

Six systems have been reported for MgH, of which the 5211 Å. and 2430 Å. systems are the most prominent.

5211 Å. SYSTEM, $^2H \rightarrow ^2\Sigma$, ground state

References. A. Guntzsch, *Dissertation, Stockholm.* (1939).

W. W. Watson and P. Rudnick, *Astrophys. J.*, **63**, 20. (1926).

W. W. Watson and P. Rudnick, *P.R.*, **29**, 413. (1927).

Bands degraded to the violet with P, Q and R branches consisting of narrow doublets. Obtained in emission in the magnesium arc in hydrogen, in discharge tubes containing magnesium vapour and hydrogen and in absorption in spectra of sun spots. See Plate 5.

v', v''	Heads	
	P	Q
0, 2	6083	
0, 1	5621.4	5609.5
1, 2	5568.3	5549.9
2, 3	5516.4	

MgH (*contd.*)

v', v''	Heads	
	P	Q
0, 0	5211.0	5186.4
1, 1	5182.3	
2, 2	5155.2	
1, 0	4845	

2430 A. SYSTEM, ${}^2\Pi \rightarrow {}^2\Sigma$, ground state

References. R. W. B. Pearse, *P.R.S.*, **122**, 442. (1929)†.

A. Guntch, *Z.P.*, **93**, 534. (1935).

L. A. Turner and W. T. Harris, *P.R.*, **52**, 626. (1937).

Bands degraded to the violet similar in appearance to the above bands, except that the doubling is much smaller. They occur under similar circumstances.

v', v''	Heads	
	P	Q
0, 1	2515.3	2510.5
1, 2		2495
0, 0	2429.2	2424.1
1, 1		2413.0
1, 0		2332

4550 A. SYSTEM, ${}^2\Pi \rightarrow {}^2\Pi$

Reference. A. Guntch, *Z.P.*, **87**, 312. (1934).

Weak bands of headless type with P and R branches composed of narrow doublets.

v', v''	Origins
0, 0	4553
1, 1	4535

4405 A. SYSTEM, ${}^2\Sigma \rightarrow {}^2\Pi$

Reference. A. Guntch, *Z.P.*, **104**, 584. (1937).

Band with two strong heads degraded to the violet.

v', v''	Heads			
	Q ₁	Q ₂	P ₁	P ₂
0, 0	4371.9	4373.0	4404.5	4404.6

2590 A. SYSTEM, ${}^2\Sigma \rightarrow {}^2\Sigma$

Reference. A. Guntch, *Z.P.*, **104**, 584. (1937).

Band with P and R branches. The R branch shows a peculiar crowding of lines at 2590.4 which gives an intensity maximum without forming a head. Obtained in absorption and emission.

v', v''	Origin
0, 0	2597

2348 A. SYSTEM

A band with a Q branch obtained under the same conditions as the above. Assignment somewhat doubtful.

MgH⁺

- References.* A. Guntch, *Dissertation, Stockholm.* (1939).
 A. Guntch, *Z.P.*, **107**, 420. (1937).
 R. W. B. Pearse, *P.R.S.*, **125**, 157. (1929).

2806 A. SYSTEM, $^1\Sigma \rightarrow ^1\Sigma$

An extensive system of bands each with a single P and single R branch. Obtained from a magnesium arc in hydrogen at low pressures or from a discharge tube containing magnesium vapour and hydrogen under conditions favouring ionisation. See Plate 5.

		Origins of Strongest Bands		
v', v''	λ	v', v''	λ	
0, 4	3388.8	0, 0	2805.8	
0, 3	3232.5	1, 0	2720.5	
0, 2	3083.0	2, 0	2641.3	
0, 1	2940.6	3, 0	2567.9	
1, 1	2847.0	4, 0	2499.7	

 $^1\Pi \rightarrow ^1\Sigma$

Bands degraded to the red, each with single P, Q and R branches.

v', v''	R Heads	Q Heads
0, 2	2142	2144
0, 3	2211	2214
0, 4	2284	2285
0, 5	2357	2358

MgI

- Occurrence.* In absorption, and in flames.
Appearance. Degraded to violet. Marked sequences.
Reference. F. Morgan, *P.R.*, **50**, 603. (1936).

λ	
4163.7	head of (0, 1) sequence.
4110.3	head of strong (0, 0) sequence.
4057.3	head of (1, 0) sequence.

Walters and Barratt (*P.R.S.*, **118**, 120 (1928)) obtained these bands and others at 3983 (strong, deg. V), 3951 (strong, deg. red), 3927, 3902, 3657, 3628, 3602, etc., in absorption, but the assignment to MgI does not seem quite certain.

MgO

There is a strong green system due to MgO, and a weaker system in the red. A weak and complex system of bands in the near ultra-violet is also most probably due to MgO.

RED SYSTEM

- Occurrence.* Core of magnesium arc in air, and burning magnesium ribbon.
Appearance. Single-headed bands, degraded to violet. Sequences not very obvious.
Transition. $^1\Sigma \rightarrow \Pi^1$, probably not ground state.
References. P. C. Mahanti, *P.R.*, **42**, 609. (1932)†.
 P. C. Mahanti, *Indian J. Phys.*, **9**, 455. (1935).
 A. Lagerqvist and U. Uhler, *Nature, Lond.*, **164**, 665. (1949).

MgO (contd.)

The following are a few of the strongest bands :—

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
6581.0	3	0, 2	6060.3	6	0, 0	5518.8	4	2, 0
6311.7	4	0, 1	5775.5	5	1, 0	5475.9	3	3, 1
6246.4	3	1, 2	5726.3	3	2, 1	5285.7	3	3, 0

GREEN SYSTEM

Occurrence. Mg arc in air, burning Mg ribbon, and in flames.

Appearance. Degraded to violet. Very marked (0, 0) sequence.

Transition. $^1\Sigma \rightarrow ^1\Sigma$.

References. P. C. Mahanti, *P.R.*, **42**, 609. (1932).

A. Lagerqvist, *Ark. Mat. Astr. Fys.*, **29A**, No. 25. (1943)†.

A few weak bands are omitted.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
5206.0	4	0, 1	4996.7	9	1, 1	4935.3	4	6, 6
5192.0	4	1, 2	4985.9	8	2, 2	4923.9	3	7, 7
5177.4	3	2, 3	4974.5	7	3, 3	4818.5	3	1, 0*
5162.5	3	3, 4	4962.1	6	4, 4	4810.1	3	2, 1
5146.8	3	4, 5	4949.5	5	5, 5	4801.5	3	3, 2
5007.3	10	0, 0						

* Some authors (*e.g.*, Barrow) have reported a weak band at 4825A. ; this may be the (1, 0).

ULTRA-VIOLET SYSTEM

Occurrence. Mg ribbon burning in air, also in absorption in flames of pyrotechnic compositions.

Appearance. Complex system with bands degraded in either direction. Strongest structure 3860–3810 A. and around 3730 A.

Reference. R. F. Barrow and D. V. Crawford, *Proc. Phys. Soc.*, **57**, 12. (1945)†.

The following are a few of the more important heads ; the direction of degradation is indicated.

λ	I	λ	I	λ	I	λ	I
3856.3 V	6	3845.1 V	7	3810.3 R	5	3724.8 V	9
3855.0 V	5	3842.3 V	6	3805.3 R	5	3721.4 V	10
3849.8 V	8	3816.5 R	5	3731.9 V	7	3721.0 V	9
3848.5 V	8	3815.6 R	5	3725.9 V	8	3720.7 V	10

MnBr

Occurrence. Manganous bromide in high-frequency discharge. Also in absorption by strongly heated MnBr_2 .

References. W. Müller, *Helv. Phys. Acta.*, **16**, 1. (1943).

W. Müller, *Dissertation, Basle.* (1943)†.

P. Mesnage, *Thesis for Doctorate, Paris.* (1938).

VIOLET SYSTEM, 3650–4050 A.

This is due to a $^7\Pi \rightarrow ^7\Pi$ transition, and the band structure is very complex. Most of the heads are degraded to shorter wave-lengths. The bands of the (0, 0) sequence, which is divided into nineteen sub-bands, lie between 3834 and 3771 A.

MnBr (*contd.*)

Weaker sequences, (3, 0), (2, 0), (1, 0), (0, 1), (0, 2) and (0, 3) lie on either side of the (0, 0) group. The strongest heads reported by Mesnage are $\lambda\lambda 3866\cdot 0$, $3823\cdot 5$, $3772\cdot 1$ and $3720\cdot 5$.

BLUE-GREEN SYSTEM, 4900–5100 Å.

It is not certain whether this is due to MnBr or MnBr₂. Müller says there are three wide bands in this region. The following are the strongest heads listed by Mesnage :—

λ	<i>I</i>
5086·9 V	8
5081·0 M	15
5075·0 M	9
5072·5 M	7
4993·5 R	10

Note added in proof.

J. Bacher (*Helv. Phys. Acta.*, **21**, 379 (1948)) † has made a detailed analysis of the ultra-violet or β system and shown that the transition is really ${}^7\Pi \rightarrow {}^7\Sigma$. The strongest heads in the (0, 0) sequence are at $\lambda\lambda 3823\cdot 5$, $3816\cdot 5$, $3809\cdot 6$, $3808\cdot 1$, $3800\cdot 9$, $3793\cdot 9$, $3783\cdot 1$, $3781\cdot 9$.

MnCl or MnCl₂

Occurrence. Manganous chloride in high-frequency discharge. Also in absorption by strongly heated MnCl₂.

References. W. Müller, *Helv. Phys. Acta.*, **16**, 1. (1943).

W. Müller, *Dissertation, Basle.* (1943) †.

P. Mesnage, *Thesis for Doctorate, Paris.* (1938).

ULTRA-VIOLET SYSTEM, 3500–4000 Å.

This system is due to the diatomic chloride, MnCl, and corresponds to a ${}^7\Pi \rightarrow {}^7\Pi$ transition. The (0, 0) sequence is the strongest and lies between 3716 and 3670 Å. Owing to the high multiplicity the structure is very complex and each band is composed of nineteen sub-bands. The (0, 1) sequence, 3770–3739 Å., and the (1, 0) sequence, 3661–3621 Å., are also fairly strong, and weaker sequences (0, 4), (0, 3), (0, 2), (2, 0) and (3, 0) have been observed. The heads are degraded to shorter wave-lengths. The following sequence heads are fairly outstanding :—

λ	<i>I</i>	Sequence
3661·3	8	(1, 0)
3716·8	10	(0, 0)
3770·4	8	(0, 1)

The following are the strongest heads in the (0, 0) sequence, $\lambda\lambda 3716\cdot 8$, $3712\cdot 6$, $3710\cdot 9$, $3706\cdot 3$, $3702\cdot 2$, $3700\cdot 1$, $3695\cdot 6$, $3694\cdot 0$, $3689\cdot 3$, $3683\cdot 1$, $3676\cdot 7$.

BLUE-VIOLET SYSTEM, 4300–4600 Å.

Diffuse bands. Mesnage lists maxima at $\lambda\lambda 4517\cdot 3$, $4409\cdot 5$, $4341\cdot 2$ and $4331\cdot 1$.

MnCl or MnCl₂ (contd.)

BLUE-GREEN SYSTEM, 4800–5100 Å.

The following are the strongest bands reported by Mesnage; R, V and M indicate degraded to red, violet, or maximum of headless band:—

λ	I	λ	I
5043.5 V	5	5025.3 M	5
5038.8 M	10	5018.9 R	6
5033.7 M	5	5013.0 R	4
5026.3 M	5	4977.5 M	5

Note added in proof.

J. Bacher (*Helv. Phys. Acta.*, **21**, 379 (1948)†) has given a detailed analysis of the ultra-violet system and shown that the transition is really ${}^7\Pi \rightarrow {}^7\Sigma$. There is also mention of absorption bands around 2500 Å.

MnF

There is a strong system due to MnF around 3500 Å. This has been obtained in emission in a special discharge tube using flowing MnF₂ vapour, and also in absorption. There is also mention of emission around 5000 Å., and absorption around 2500–2400 Å.

Reference. J. Bacher, *Helv. Phys. Acta.*, **21**, 379. (1948)†.

 β SYSTEM, 3500 Å.

Appearance. Well marked sequences, of which the (0, 0) is the strongest. Each sequence contains numerous heads. Degraded to shorter wave-lengths.

Transition. ${}^7\Pi \rightarrow {}^7\Sigma$.

The following are the sequence heads, 3671 (0, 2), 3595 (0, 1), 3517 (0, 0), 3439 (1, 0), 3360 (2, 0).

The strongest heads in the (0, 0) sequence are at $\lambda\lambda$ 3517.8, 3516.7, 3514.3, 3513.0.

MnH

References. R. W. B. Pearse and A. G. Gaydon, *Proc. Phys. Soc.*, **50**, 201. (1938)†.

T. E. Nevin, *Proc. Roy. Irish Acad.*, **A48**, 1. (1942)†.

T. E. Nevin, *Proc. Roy. Irish Acad.*, **A50**, 123. (1945).

Occurrence. The spectrum of MnH has been observed in high-tension arc between manganese electrodes in a hydrogen flame and in a discharge tube containing hydrogen and manganese vapour. A. Heimer has observed the spectrum in emission and absorption using a furnace. See Plate 5.

5677 Å. SYSTEM, ${}^7\Pi \rightarrow {}^7\Sigma$

Bands degraded to the violet of very complex structure.

v', v''	λ	Heads		λ	I
		I			
0, 1	6237	2			
0, 0	5677	10	5720	2	
1, 0	5172	4			

MnH (*contd.*)**4800 A. SYSTEM**

Strong band degraded to the red. Very complex in structure.

v', v''	λ	Heads		λ	I
		λ	I		
0, 0 ?	4741	4		4794	5

4500 A. SYSTEM

Open band structure degraded to the red. The strong lines fall into five branches, which close up to a weak head about $\lambda 4480$.

λ	Head
	I
4480	1

MnI

Occurrence. In absorption by heated MnI_2 vapour.

Appearance. Degraded to shorter wave-lengths. A complex system around 4050 A.

Transition. Probably ${}^7\Pi \rightarrow {}^7\Sigma$.

Reference. J. Bacher, *Helv. Phys. Acta.*, **21**, 379. (1948)†.

The following are amongst the strongest heads, $\lambda\lambda 4108.3, 4086.7, 4079.8, 4068.8, 4047.8, 4027.7, 4009.2, 3990.9$.

MnO

Occurrence. In flames and in manganese arc in air. Has been observed in furnaces.

Appearance. Degraded to red. Well-marked sequences.

Reference. A. K. S. Gupta, *Z.P.*, **91**, 471. (1934)†.

Only the strong bands are listed below. Intensities are our own estimates from Gupta's published photographs. S denotes head of sequence.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
6523.8	3	2, 5	5609.5	10	1, 1	5192.3	4	3, 1
6203.2	6	2, 4	5586.4	10	0, 0 S	5158.1	2	2, 0 S
6175.9	7	1, 3	5423.8	7	3, 2	5051.0	3	5, 2
6154.9	7	0, 2 S	5389.4	8	2, 1	5013.0	3	4, 1
5880.3	10	1, 2	5359.4	9	1, 0 S	4976.4	2	3, 0 S
5859.6	9	0, 1 S	5228.5	5	4, 2			

MoO ?

Continuous emission and faint bands in the region 6500–6100 A. have been observed when molybdenum oxide MoO_3 is introduced into a flame or arc.

Reference. G. Piccardi, *Accad. Lincei Atti.*, **17**, 654. (1933).

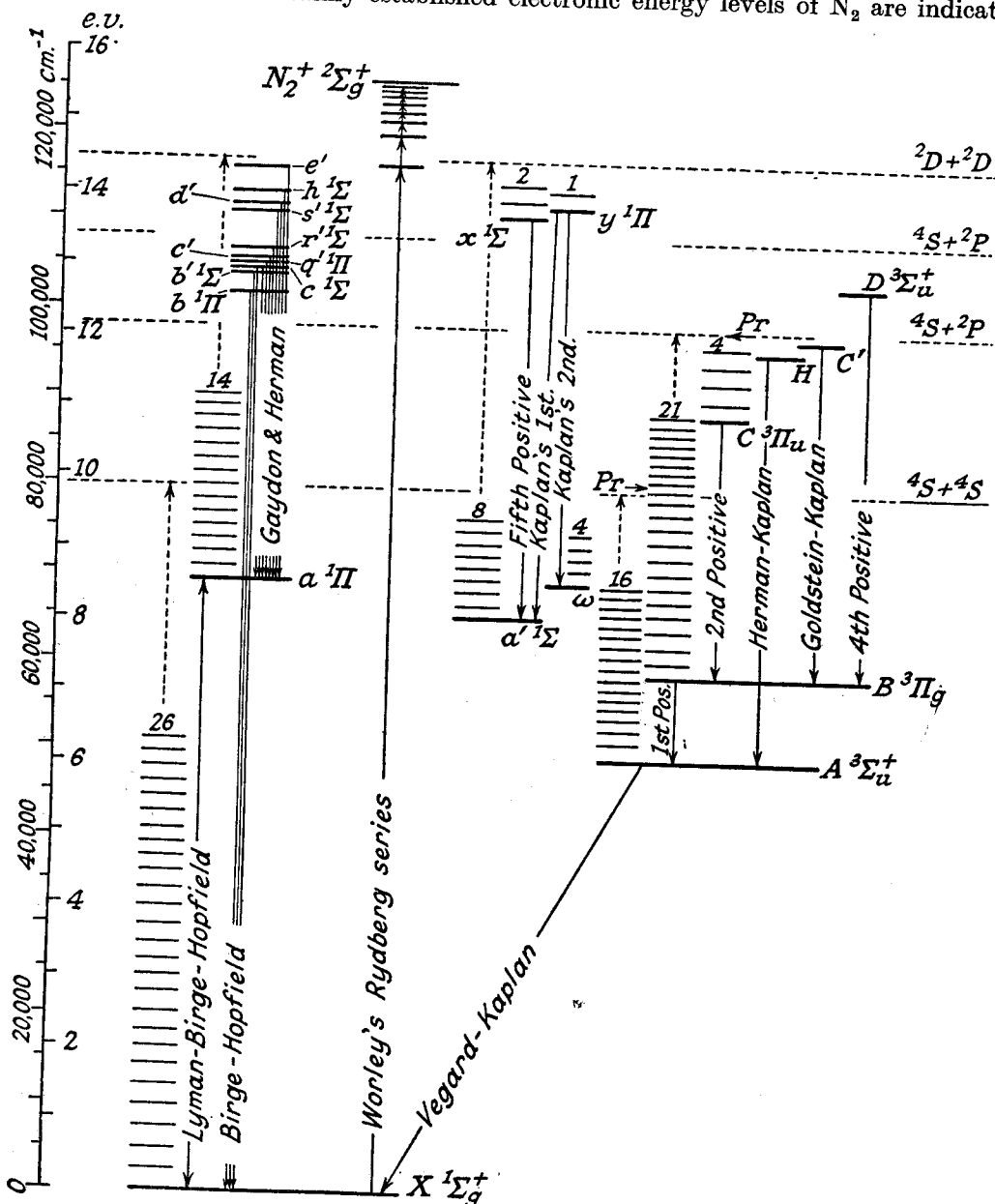
N₂

There are a large number of band systems attributed to the neutral nitrogen molecule. In emission the first and second positive systems are the most readily developed, the second positive being the more easily obtained in a discharge through air (such as a leak in a discharge tube), the presence of oxygen appearing to favour this system relatively to the first positive bands. Other systems which appear in emission are the Fourth Positive bands, the Vegard-Kaplan bands, a part of the Lyman-Birge-Hopfield system, van der Ziel's system, and some weak systems

N_2 (contd.)

reported by Kaplan, Gaydon and Herman. Lyman, Birge and Hopfield, and Worley have observed several systems in absorption in the vacuum ultra-violet.

All the most certainly established electronic energy levels of N_2 are indicated



in the accompanying figure. Some levels of very high energy involved in Hopfield's Rydberg series and some levels obtained from vacuum ultra-violet absorption bands by Worley, whose energies are not quite certain, have been omitted. The exact energies of the states a' , w , x and y relative to the ground state are unknown. The letters c' , d' and e' have been used for the upper levels of the systems denoted respectively as δ , θ and η by Herman. The level h is to be identified with Gaydon's level t' ,

N_2 (contd.)

and c with p' . For a discussion of the energy levels of N_2 see Gaydon (*Proc. Roy. Soc.*, **A182**, 286 (1944)), Gaydon and Worley (*Nature*, **153**, 747 (1944)), Herzberg (*Phys. Rev.*, **69**, 362 (1946)) and Gaydon and Herman (*Proc. Phys. Soc.*, **58**, 292 (1946)).

The heavier longer horizontal lines represent the electronic energy levels (with $v = 0$), while the thinner shorter lines indicate vibrational levels of these states where known. The highest known vibrational levels are indicated by the value of the vibrational quantum number v . "Pr." indicates onset of predissociation. The limits are inserted on the assumption that the dissociation energy of N_2 is 9.764 e.v.

FIRST POSITIVE SYSTEM

Occurrence. In the positive column of discharge tubes containing nitrogen or air. The bands appear very readily.

Appearance. Degraded to the violet. Under small dispersion the appearance is of waves of regularly spaced triple-headed bands strongest in the orange, the red and the yellow-green. Under large dispersion the rotational structure is seen to be complex, and there are several heads to each band. See Plate 3.

Transition. $B^3\Pi \rightarrow A^3\Sigma$.

References. A. Fowler and R. J. Strutt, *P.R.S.*, **85**, 377. (1911)†.

A. H. Poetker, *P.R.*, **30**, 812. (1928)†.

H. Birkenbeil, *Z.P.*, **88**, 1. (1934).

In the following table the first heads of the bands as listed by Birkenbeil (which include Poetker's measurements in the infra-red) are given with the addition of those listed by Fowler and Strutt as occurring strongly in the nitrogen afterglow. The intensities I_a and I_b are for an ordinary discharge and for the nitrogen afterglow respectively in which the intensity distributions are very different. The values of I_a in the infra-red are thermocouple measurements by Poetker, and in the visible the intensities are our own estimates from Fowler and Strutt's published photographs.

λ	I_a	I_b	v', v''	λ	I_a	I_b	v', v''
10420	10		0, 0	7059.0	2		8, 6
9860	1		2, 2	6967.8	1		9, 7
9599	3		3, 3	6875.0	2		3, 0
9362	3		4, 4	6788.6	6		4, 1
9133	2		5, 5	6704.8	8		5, 2
8911.6	10		1, 0	6623.6	9		6, 3
8722.3	8		2, 1	6544.8	10		7, 4
8541.8	6		3, 2	6468.5	10		8, 5
8369.2	2		4, 3	6394.7	9		9, 6
8204.8	3		5, 4	6322.9	7	2	10, 7
8047.4	2		6, 5	6252.8	3	5	11, 8
7896.4	2		7, 6	6185.2	3	1	12, 9
7753.2	6		2, 0	6127.4	3		5, 1
7626.2	7		3, 1	6069.7	7		6, 2
7503.9	7		4, 2	6013.6	7		7, 3
7386.6	5		5, 3	5959.0	8		8, 4
7273.3	3		6, 4	5906.0	8		9, 5
7164.8	2		7, 5	5854.4	8	4	10, 6

N_2 (contd.)

λ	I_a	I_b	v', v''	λ	I_a	I_b	v', v''
5804.3	7	10	11, 7	5478.5	2		9, 4
5755.2	7	8	12, 8	5442.3	3	1	10, 5
5632.7	1		5, 0	5407.1	3	5	11, 6
5592.9	1		6, 1	5372.8	3	5	12, 7
5553.7	1		7, 2	5053.6		2	11, 5
5515.6	2		8, 3	5030.8		2	12, 6

SECOND POSITIVE SYSTEM

Occurrence. In the positive column of discharge tubes containing nitrogen or air and in arcs at low pressure. The bands appear very readily and are of frequent occurrence as an impurity.

Appearance. Degraded to shorter wave-lengths. Close triple-headed bands forming fairly obvious sequences. See Plate 3.

Transition. $C^3\Pi \rightarrow B^3\Pi$.

References. R. Mecke and P. Lindau, *Phys. Zeit.*, **25**, 277. (1924).

D. Coster, H. Brons and A. van der Ziel, *Z.P.*, **84**, 304. (1933).

The following measurements are by R. C. Pankhurst and A. G. Gaydon from spectrograms taken on a Hilger E.1 and on a 20-ft. concave grating spectrograph:—

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
4976.4	0	4, 11	4059.4	8	0, 3 ⁷	3371.3	10	0, 0 ⁷
4916.8	0	1, 7	3998.4	9	1, 4	3339	2*	1, 1
4814.7	1	2, 8	3943.0	8	2, 5	3309	2*	2, 2
4723.5	1	3, 9	3894.6	7	3, 6	3285.3	3	3, 3
4667.3	0	0, 5 ⁷	3857.9	5	4, 7	3268.1	4	4, 4 [*]
4649.4	1	4, 10	3804.9	10	0, 2 ⁷	3159.3	9	1, 0 ⁷
4574.3	2	1, 6	3755.4	10	1, 3	3136.0	8	2, 1
4490.2	3	2, 7	3710.5	8	2, 4	3116.7	6	3, 2
4416.7	3	3, 8	3671.9	6	3, 5 ⁷	3104.0	3	4, 3
4355.0	3	4, 9 ⁷	3641.7	3	4, 6	2976.8	6	2, 0 ⁷
4343.6	4	0, 4	3576.9	10	0, 1 ⁷	2962.0	6	3, 1
4269.7	5	1, 5	3536.7	8	1, 2	2953.2	6	4, 2 ⁷
4200.5	6	2, 6	3500.5	4	2, 3	2819.8	1	3, 0 ⁷
4141.8	5	3, 7	3469	0	3, 4	2814.3	1	4, 1
4094.8	4	4, 8	3446	0	4, 5 ⁷			

* The intensities of the (1, 1) and (2, 2) bands relative to the (0, 0) band seem to vary considerably in different sources. In some sources using pure nitrogen they are often weak, but on spectrograms of a discharge through air they may be quite strong.

On very heavy exposures, weak heads of the isotope molecule, $N^{14}N^{15}$, may be observed in front of the main heads of the (1, 0) and (2, 0) sequences.

FOURTH POSITIVE SYSTEM

Occurrence. In mildly condensed discharge through nitrogen.

Appearance. Degraded to shorter wave-lengths. A single progression of bands each with five close heads. See Plate 6.

Transition. $D^3\Sigma_u^+ \rightarrow B^3\Pi$.

N_2 (contd).

References. A. Fowler and R. J. Strutt, *P.R.S.*, 85, 377. (1911)†.

L. Gerö and R. Schmid, *Z.P.*, 116, 598. (1940).

Bands as listed by Fowler and Strutt :—

λ	I	v', v''	λ	I	v', v''
2903.9	1	0, 6	2448.0	10	0, 2
2902.0			2447.0		
2900.3			2445.6		
2898.1			2444.0		
2896.6			2442.8		
2777.9	2	0, 5	2351.4	6	0, 1
2776.5			2350.3		
2775.1			2349.0		
2772.8			2347.5		
2771.4			2346.4		
2660.5	5	0, 4	2260.8	2	0, 0
2659.3			2259.6		
2657.9			2258.4		
2655.8			2257.1		
2654.5			2256.0		
2550.7	8	0, 3			
2549.7					
2548.4					
2546.6					
2545.3					

VEGARD-KAPLAN BANDS

Occurrence. This is a relatively weak "intercombination" system, and is only observed strongly under rather special conditions of excitation. The system was first reported by Vegard in the spectrum of the luminescence of solid nitrogen. Kaplan produced the bands in a special discharge tube consisting of a short length of 1 mm. capillary and a 500 c.c. bulb; an uncondensed discharge was used and the bands also appeared in the afterglow. Bernard has succeeded in observing another part of the system by exciting a mixture of nitrogen and argon with an electron beam. Some of the bands occur in the aurora and the night sky.

Appearance. Degraded to the red. Kaplan and Bernard report the bands as single headed, but in the luminescence of solid nitrogen Vegard observed a weak and a strong head to each.

Transition. $A^3\Sigma \rightarrow X^1\Sigma$, ground state.

References. J. Kaplan, *P.R.*, 45, 675. (1934)†, and numerous short letters and abstracts, mostly in *Phys. Rev.*

R. Bernard, *C.R. Acad. Sci. Paris*, 200, 2074. (1935).

The following are the bands as observed by Kaplan; intensities are our own estimates from his small published photograph :—

N_2 (contd.)

λ	I	v', v''	λ	I	v', v''
3424.6	4	1, 10	2603.8	10	0, 5
3197.5	5	1, 9	2560.1	2	2, 6
2997.0	2	1, 8	2509.8	6	1, 5
2935.7	9	0, 7	2461.6	9	0, 4
2760.6	9	0, 6	2424.2	0	2, 5
2710.1	0	2, 7	2377.5	7	1, 4
2655.5	1	1, 6	2332.8	4	0, 3

The bands observed by Vegard from solid nitrogen have their stronger heads 125 cm.^{-1} (around 10 Å.) to the red of the heads listed by Kaplan.

The following are the strong bands as observed by Bernard :—

λ	I	v', v''	λ	I	v', v''
5060.1	4	0, 14	4072.5	3	2, 13
4837.1	8	2, 15	3979.1	3	1, 12
4649.7	4	4, 16	3940.3	4	7, 16
4616.5	3	7, 18	3889.2	4	0, 11
4535.5	5	3, 15	3854.7	3	3, 13
4319.8	2	1, 13	3603.0	4	0, 10
4171.2	4	3, 14	3502.7	3	2, 11

LYMAN-BIRGE-HOPFIELD SYSTEM

Occurrence. The main part of the system, which lies in the vacuum ultra-violet, is readily observed in absorption and emission. With a high current-density discharge the system can be extended to longer wave-lengths, and weak bands may be observed as far as 2600 Å.

Appearance. Degraded to the red. Apparently single-headed bands.

Transition. $a \ ^1\Pi_g \rightarrow X \ ^1\Sigma_g^+$.

References. R. T. Birge and J. J. Hopfield, *Astrophys. J.*, **68**, 257. (1928)†.

E. T. S. Appleyard, *P.R.*, **41**, 254. (1934).

R. Herman, *Thesis, Paris*. (1945)†.

The following bands have been recorded beyond 2000 Å. :—

λ	v', v''	λ	v', v''	λ	v', v''	λ	v', v''
2601.5	15, 27	2425.1	11, 22	2278.3	3, 14	*2125.9	5, 14
2565.2	13, 25	2406.3	10, 21	*2271.7	8, 18	2108.1	4, 13
2528.3	11, 23	2387.6	9, 20	2253.4	7, 17	2089.7	3, 12
2509.7	10, 22	2369.0	8, 19	2234.8	6, 16	2059.0	6, 14
2491.3	9, 21	2366.7	13, 23	2216.6	5, 15	*2041.2	5, 13
2481.7	14, 25	*2328.3	11, 21	2198.7	4, 14	2023.5	4, 12
2472.6	8, 20	*2309.4	10, 20	2181.1	3, 13	2006.0	3, 11
2462.9	13, 24	*2290.5	9, 19	2144.0	6, 15		

* These bands may be relatively strong.

FIFTH POSITIVE (VAN DER ZIEL) SYSTEM

Occurrence. High current-density discharge or mildly condensed discharge through nitrogen.

Appearance. Degraded to shorter wave-lengths. Single headed.

N_2 (contd.)Transition. $x \ ^1\Sigma \rightarrow a' \ ^1\Sigma$.References. A. van der Ziel, *Physica*, **1**, 513. (1934).A. G. Gaydon, *P.R.S.*, **182**, 286. (1944)†.

Most of the following measurements and intensities are by Gaydon, who has modified van der Ziel's vibrational analysis.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
2781.6	3	1, 8	2525.6	2	0, 4	2235.8	3	2, 3
2743.0	1	2, 9	2496.9	3	1, 5	2198.9	4	0, 0
2681.2	5	1, 7	2469.7	4	2, 6	2181.5	4	1, 1
2647.0	2	2, 8	2411.7	7	1, 4	2165.1	5	2, 2
2619.3	4	0, 5	2353.6	4	0, 2	2112.1	5	1, 0
2586.5	7	1, 6	2331.0	2	1, 3	2098	2	2, 1
2556.0	1	2, 7	2274.2	6	0, 1	2033.6	5	2, 0

Some bands of this system are masked by other bands of N_2 .

GAYDON'S AND HERMAN'S SINGLET SYSTEMS

Eight progressions of bands, probably due to eight independent systems, all involving transitions to $a \ ^1\Pi$ have been obtained.

Occurrence. These are all weak systems. Gaydon obtained most of them from a mildly condensed discharge through N_2 , while Herman also independently recorded most of the bands using an ordinary discharge at low pressure through a very long tube (25 m.). See Plate 6.

References. A. G. Gaydon, *P.R.S.*, **182**, 286. (1944)†.R. Herman, *Thesis, Paris*. (1944)†.A. G. Gaydon and R. Herman, *Proc. Phys. Soc.*, **58**, 292. (1946).J. Janin, *Cahiers de Physique*, No. 16, p. 16. (1943).35371 $cm.^{-1}$ progression. $c \ ^1\Sigma \rightarrow a \ ^1\Pi$.

This is Gaydon's P system or Herman's ζ . The bands are degraded to shorter wave-lengths and are close double-headed.

λ	v', v''
3118.6	0, 2
2967.0	0, 1
2827.1	0, 0

35761 $cm.^{-1}$ progression. $c' \rightarrow a \ ^1\Pi$.

This is the $v' = 0$ progression of Herman's δ system. Degraded to the red.

λ	v', v''
3240.9	0, 3
3079.8	0, 2
2932.0	0, 1
2795.5	0, 0

N_2 (contd.)

36394 cm^{-1} progression. $q' \ ^1\Pi \rightarrow a \ ^1\Pi$.

This is Gaydon's *Q* system or the $v' = 1$ progression of Herman's δ system. Degraded to the red. Sharp single heads.

λ	v', v''	λ	v', v''
3174.8	0, 3	2877.9	0, 1
3020.4	0, 2	2746.2	0, 0

37417 cm^{-1} progression. $r' \ ^1\Sigma \rightarrow a \ ^1\Pi$.

Gaydon's *R* system. Very weakly degraded to red. Bands show strong piled-up *Q* branch and *P* and *R* lines on either side. The (0, 0) band of this system is the strongest of all the bands of these systems recorded by Gaydon.

Q heads, (0, 0) 2671.7 A., (0, 1) 2796.0 A.

41705 cm^{-1} progression. $s' \ ^1\Sigma \rightarrow a \ ^1\Pi$.

Gaydon's *S* system. Slightly degraded to the red. Strong *Q* and weak *R* heads.

δ *Q* heads, (0, 0) 2397.1, (0, 1) 2496.8, (0, 2) 2603.3.

42373 cm^{-1} progression. $d' \rightarrow a \ ^1\Pi$.

Herman's θ system. An adequate description of these bands has not been published, but they may show several close heads.

λ	v', v''
2558	0, 2
2455.1	0, 1
2358.8	0, 0

43818 cm^{-1} progression. $h \ ^1\Sigma \rightarrow a \ ^1\Pi$.

Gaydon's *T* system or Herman's ϵ . Bands very weakly degraded to red. Strong heads to piled-up *Q* branches. It is just possible that this is the $v' = 1$ progression of the *S* system (41705 cm^{-1} progression).

λ	v', v''	λ	v', v''
2795.6	0, 5	2371.6	0, 1
2678.7	0, 4	2281.5	0, 0
2569.6	0, 3		

46611 cm^{-1} progression. $e' \rightarrow a \ ^1\Pi$.

Herman's η system. Degraded to shorter wave-lengths. Single headed.

λ	v', v''	λ	v', v''
2699.9	0, 6	*2397.8	0, 3
2592.8	0, 5	2308.6	0, 2
2492.4	0, 4	2224.4	0, 1

* This band coincides with the stronger (0, 0) band of the 41705 cm^{-1} system.

N₂ (contd.)

KAPLAN'S FIRST SYSTEM, $y\ ^1\Pi \rightarrow a'\ ^1\Sigma$

Occurrence. A weak system obtained in a mildly condensed discharge (Gaydon), in a long tube (Herman) or in a special discharge tube for studying afterglow effects (Kaplan).

Appearance. Single-headed bands. Degraded to shorter wave-lengths.

References. J. Kaplan, *P.R.*, **46**, 631 (1934); **47**, 259. (1935).

A. G. Gaydon, *P.R.S.*, **182**, 286. (1944)†.

R. Herman, *Thesis, Paris*. (1944).

A. G. Gaydon and R. Herman, *Proc. Phys. Soc.*, **58**, 292. (1946).

λ	I	v', v''	λ	I	v', v''
2466.0	2	0, 4	2288.5	1	1, 3
2381.7	3	0, 3	2225.8	5	0, 1
2366.4	2	1, 4	2153.6	4	0, 0
2301.9	4	0, 2			

KAPLAN'S SECOND SYSTEM (HERMAN'S α) $y\ ^1\Pi \rightarrow w$

Appearance. Strong single heads. Degraded to shorter wave-lengths.

Occurrence and References as for Kaplan's First System.

λ	I	v', v''	λ	I	v', v''
2854.9	?	0, 5	2536.6	5	0, 2
2741.9	3	0, 4	2522.3	3	1, 3
2722.0	3	1, 5	2431.0	?	1, 2
2636.2	5	0, 3	2354.5	4	0, 0
2619.3	? 5	1, 4	2263.4	4	1, 0

HERMAN-KAPLAN SYSTEM

Occurrence. A weak system originally reported by Kaplan (Third System) in his tube for examining the afterglow, and extended and analysed by Herman using a very long discharge tube.

Appearance. Degraded to shorter wave-lengths.

Transition. To the A $^3\Sigma$ level, from an unknown level here denoted H.

References. J. Kaplan, *P.R.*, **47**, 259. (1935).

R. Herman, *Thesis, Paris*. (1944).

λ	v', v''	λ	v', v''	λ	v', v''
2733.2	0, 7	*2471.4	0, 4	2272.9	1, 3
2642.1	0, 6	2419.8	1, 5	*2242.3	0, 1
2554.9	0, 5	*2391.6	0, 3	2203.8	1, 2
2497.8	1, 6	*2315.3	0, 2	2137.6	1, 1

* These bands may be relatively strong.

GOLDSTEIN-KAPLAN BANDS

Occurrence. Silent (ozoniser type) discharge or Tesla discharge through N₂ at relatively high gas pressure. Also in afterglow under some conditions.

Appearance. Degraded to the red. Complex structure with several heads.

References. H. Hamada, *Phil. Mag.*, **23**, 25. (1937).

A. G. Gaydon, *Proc. Phys. Soc.*, **56**, 85. (1944)†.

N_2 (contd.)

These bands are probably due to a transition from an excited state, C' , to the $B^3\Pi$ state. Hamada gave the following wave-lengths and analysis, but no intensities:—

2863.5 (0, 2), 3005.4 (0, 3), 3025.8 (1, 4), 3159.2 (0, 4), 3178.4 (1, 5), 3326.1 (0, 5), 3504.0 (0, 6), 3707.1 (0, 7), 3925.4 (0, 8), 4166.0 (0, 9), 4432.2 (0, 10), 4728.0 (0, 11), 5058.6 (0, 12).

On Gaydon's plates the ultra-violet bands were absent or masked, and it seems likely that they belong to a different system. He obtained the following three heads for each band:—

λ	I	v', v''	λ	I	v', v''
5076.2			4446.2		
5066.7	1	0, 12	4438.8	4	0, 10
5059.4			4432.3		
4743.8			4178.2		
4735.6	3	0, 11	4171.6	5	0, 9
4728.4			4165.7		

GAYDON'S GREEN SYSTEM

Occurrence. Silent (ozoniser type) and Tesla discharge through N_2 at relatively high gas pressure. The bands are not obtained in discharges through air. They were obtained by Herman (κ system) in a very long tube.

Appearance. Degraded to the violet. Five heads, of which the fifth (shortest λ) is the strongest.

Reference. A. G. Gaydon, *Proc. Phys. Soc.*, **56**, 85. (1944)†.

The nature of the electronic transition is unknown. The vibrational analysis is provisional. All five heads are given for two of the strongest bands, and the fifth head only for other bands.

λ	v', v''	λ	v', v''
(6340)	0, 3	5326.9	
		5320.7	
(6075)	0, 2	5316.7	
		5312.9	
*5814.7	0, 1	*5309.5	1, 0
5595.0		5270.5	2, 1
5587.6			
5582.9		5073	2, 0
5579.3			
*5574.8	0, 0		

* Strongest heads.

 N_2^+

MAIN SYSTEM

Occurrence. In discharge tubes at very low pressure or at moderate pressure in presence of excess of helium, in hollow cathode, and in negative glow.

N_2^+ (contd.)

Appearance. Strong bands are degraded to shorter wave-lengths, but a few weak bands are degraded to the red. Single-headed. See Plate 3.

Transition. ${}^2\Sigma \rightarrow {}^2\Sigma$, ground state.

References. T. R. Merton and J. G. Pilley, *Phil. Mag.*, **50**, 195. (1925).

D. Coster and H. H. Brons, *Z.P.*, **70**, 492. (1931).

G. Herzberg, *Ann. Phys. Lpz.*, **86**, 189. (1928).

A. E. Parker, *P.R.*, **44**, 914. (1933).

The following table is from Merton and Pilley. These bands are degraded to shorter wave-lengths. Intensities I_{he} and I_n are for Tesla coil discharge through helium containing a trace of nitrogen and for ordinary discharge through nitrogen at low pressure.

λ	I_{he}	I_n	v', v''	λ	I_{he}	I_n	v', v''
5864.7	4	0	0, 4	4199.1	4	2	2, 3
5653.1	4	1	2, 6	4166.8	3	0	3, 4
5564.1	1	0	3, 7	4140.5	2		4, 5
5485.5	5	0	4, 8	3914.4	6	6	0, 0
5228.3	7	2	0, 3	3884.3	3	1	1, 1
5148.8	4	3	1, 4	3857.9	2	2	2, 2
5076.6	7	1	2, 5	3835.4	1	1	3, 3
5012.7	3	1	3, 6	3818.1	1	0	4, 4
4957.9	5	1	4, 7	3582.1	4	3	1, 0
4709.2	4	2	0, 2	3563.9	4	0	2, 1
4651.8	4	1	1, 3	3548.9	3		3, 2
4599.7	6	2	2, 4	3538.3	2		4, 3
4554.1	4	0	3, 5	3532.6	1	0	5, 4
4515.9	6	0	4, 6	3308.0	2	1	2, 0
4490.3	2	1	5, 7	3298.7	3	1	3, 1
4278.1	8	6	0, 1	3293.4	3	0	4, 2
4236.5	7	5	1, 2				

Coster and Brons report the two bands degraded to the red :—

$$3612.4 (10, 9) \quad 3381.3 (10, 8)$$

FAR ULTRA-VIOLET SYSTEM

Occurrence. Discharge through a mixture of helium and nitrogen, or condensed discharge through N_2 .

Appearance. Degraded to red. Well-defined sequences in which the rotational and vibrational structure appears degraded in opposite directions. The bands show alternating intensities and are probably due to a ${}^2\Sigma \rightarrow {}^2\Sigma$ transition.

Reference. W. W. Watson and P. G. Koontz, *P.R.*, **46**, 32. (1934)†.

This system lies at the limit of the quartz region. Watson and Koontz give a vibrational analysis which places the system origin at 1847 A.; with this analysis the intensity distribution is anomalous. The following are the more important heads for identification :—

INDIVIDUAL BAND SYSTEMS

N_2^+ (contd.)

λ_{air}	I	λ_{vac}	I
2058.9	4	1984.5	10
2051.5	3	1979.0	8
2043.8	2	1973.3	6
2036.1	1	1967.6	6
		1913.4	9
		1909.7	7

NBr

Occurrence. In afterglow of nitrogen containing bromine.

Appearance. Three sequences of bands degraded to the violet. The system is not unlike the first positive bands of nitrogen, but on a smaller scale.

Reference. A. Elliott, *P.R.S.*, **169**, 469. (1939)†.

The following are the strong bands; the intensities are our estimates from the published photograph:—

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
6404.8	5	1, 0	6075.9	4	3, 1	5905.0	10	9, 7
6370.1	5	2, 1	6047.9	7	4, 2	5876.2	5	10, 8
6335.4	7	3, 2	6019.5	9	5, 3	5741.9	6	7, 4
6300.2	7	4, 3	5990.7	10	6, 4	5718.6	8	8, 5
6265.9	8	5, 6	5962.4	10	7, 5	5695.1	8	9, 6
6231.1	8	6, 5	5933.8	10	8, 6	5671.5	4	10, 7
6196.0	6	7, 6						

In addition, there are a few unassigned bands, but these mostly appear to be weak.

NH

Of the four systems reported, the triplet system at 3360 A. is most readily excited.

3360 A. SYSTEM, $^3\Pi \rightarrow ^3\Sigma$, ground state.

References. A. Fowler and C. C. L. Gregory, *Phil. Trans. Roy. Soc.*, **A218**, 251. (1919)†.

G. W. Funke, *Z.P.*, **96**, 787. (1935).

Bands scarcely degraded in either direction so that Q branches form a strong central maximum of intensity, while the R and P branches spread out symmetrically. Branches consist of narrow triplets whose spacing decreases with increasing rotation. Under low dispersion the Q-maxima of the (0, 0) and (1, 1) bands are often mistaken for an atomic doublet.

The system occurs under a wide range of conditions; in flames such as the ammonia-oxygen flame and moist cyanogen flame; in discharge tubes containing nitrogen and hydrogen; in low pressure arcs; controlled electron discharges; active nitrogen and chemiluminescence where nitrogen and hydrogen are both present. Also in absorption at high temperatures. See Plate 4.

v', v''	λ	} Broad Q maxima.
0, 0	3360	
1, 1	3370	

NH (*contd.*)3240 A. SYSTEM, $c^1\Pi \rightarrow a^1\Delta$

References. R. W. B. Pearse, *P.R.S.*, **143**, 112. (1933)†.

G. Nakamura and T. Shidei, *Japan J. Phys.*, **10**, 5. (1934).

Bands degraded to the red. Branches consist of very narrow doublets whose spacing increases with rotation; the R branch is much weaker than the P and Q. The system occurs in discharge tubes; in chemiluminescence and in active nitrogen where hydrogen and nitrogen are present together. See Plate 4.

v', v''	Heads	
	R	Q
0, 1	3609.6	3627.2
0, 0	3240.1	3253.4
1, 0	3035.2	3042.6

4502 A. SYSTEM, $c^1\Pi \rightarrow b^1\Sigma$

Reference. R. W. Lunt, R. W. B. Pearse and E. C. W. Smith, *P.R.S.*, **151**, 602. (1935)†.

Band degraded to the red. Single P, Q and R branches. Observed in controlled electron discharges in ammonia and in hollow cathode discharge with rapidly streaming ammonia.

v', v''	R Head	Q Head
0, 0	4502.0	4523.2

2530 A. SYSTEM, $d^1\Sigma \rightarrow c^1\Pi$

Reference. R. W. Lunt, R. W. B. Pearse and E. C. W. Smith, *P.R.S.*, **155**, 173. (1936)†.

Band degraded to the violet observed by Hori in high tension discharge through a mixture of hydrogen and nitrogen in presence of sodium or lithium. Occurs also in hollow cathode with streaming ammonia.

v', v''	P Head	Q Head
0, 0	2557.3	2530.2

NH⁺ ?

Reference. R. W. Lunt, R. W. B. Pearse and E. C. W. Smith, *Nature, Lond.*, **136**, 32. (1935). Bands at $\lambda\lambda$ 2980, 2885, 2835 and 2730 obtained in streaming NH₃ in a hollow cathode discharge.

NH₂ ? Ammonia α Band

Occurrence. In flame of ammonia burning in oxygen, and weakly in a discharge through streaming ammonia. Also in flames supported by N₂O.

Appearance. This band structure extends throughout the visible, being strongest in the yellow and green; it is responsible for the yellow-green colour of the ammonia flame. The band is of the "many-line" type, showing a very large number of fine lines, without heads or obvious regularity. The structure seems too complex for a diatomic molecule of the type of NH, and yet the experimental evidence of its

NH₂? Ammonia α Band (contd.)

production suggests that it is a decomposition product of ammonia rather than NH₃ itself which is the emitter. It seems likely to be due to NH₂.

References. W. B. Rimmer, *P.R.S.*, **103**, 696. (1923)†.

A. Fowler and J. S. Badami, *P.R.S.*, **133**, 325. (1931)†.

A. G. Gaydon, *P.R.S.*, **181**, 197. (1942)†.

Rimmer has given measurements of some 300 lines of this band, with intensities on a scale of 6. The following are the strongest lines (intensities listed as 4, 5 or 6) :—

λ	<i>I</i>	λ	<i>I</i>	λ	<i>I</i>
6332.82	6	5624.40	5	4975.05	4
6325.18	5	5621.03	5	4746.26	4
6300.81	5	5597.39	4	4743.56	4
5977.29	5	5563.62	5	4722.5	6
5972.16	4	5560.56	5	4704.00	4
5708.46	6	5547.42	4	4702.18	4
5707.00	6	5527.46	4	4680.04	5
5705.36	6	5525.04	6	4541.94	5
5697.17	4	5429.19	5	4540.37	4
5673.16	4	5384.64	5	4510.98	4
5641.17	5	5166.23	6	4465.34	4

According to Fowler and Badami, the band shows apparent heads, under small dispersion, at $\lambda\lambda 6652^*$, 6470, 6302*, 6042*, 5870, 5713*, 5575, 5436*, 5384 and 5265, the stronger features being marked by an asterisk.

There is also some band structure in the near infra-red which appears to be associated with the ammonia α band. Gaydon found that the strongest feature was a series of lines, $\lambda\lambda 7099$, 7166, 7207, 7241, 7274, 7304, and 7329 closing up to a head around 7350. There is some more structure in the region 8200–8270 A.

NH₃, Ammonia**SCHUSTER'S EMISSION BAND**

Occurrence. In uncondensed discharge through streaming ammonia.

Appearance. A strong continuum in the yellow-green with maxima at 5635 A. and 5670 A.

Reference. W. B. Rimmer, *P.R.S.*, **103**, 696. (1923)†.

ULTRA-VIOLET ABSORPTION

Occurrence. Absorption by gaseous ammonia.

Appearance. Rather diffuse double (or triple) headed bands, shaded to the red, occur in the region below 2300 A., the bands getting stronger in the shorter wave-length region. In the vacuum ultra-violet the bands are strong and well defined.

References. M. Ferrieres, *C.R. Acad. Sci. Paris*, **178**, 202. (1924).

A. B. F. Duncan, *P.R.*, **47**, 822. (1935).

The following are the maxima of the principal bands as compiled from the above references :—

NH₃, Ammonia (contd.)

λ	I	λ	I	λ	I
2245	1	2167.3	4	2086.4	5
2239		2163.7		2084.1	
2211	2	2126.5	4	2048.4	6
2206		2123.9		2045.7	
				2010.9	7

VIBRATION-ROTATION SPECTRUM

Occurrence. In absorption by gaseous ammonia.

Appearance. Bands composed of complex line-structure. The strongest band probably shows a maximum of intensity (the Q branch) at 7919 A. and perhaps a head degraded to the red at 7874 A.

Reference. R. M. Badger and R. Mecke, *Z. phys. Chem.*, **5**, 333. (1929).

λ		
6450	$5\nu_1$	weak
7919	$4\nu_1$	strong
8800	$3\nu_1 + \nu_2$	weak

NO

Four band systems of nitric oxide are well known in both emission and absorption. They are known as the β , γ , δ and ϵ systems. The γ system is the most readily obtained with quartz instruments; the δ and ϵ systems are stronger, but lie at the limit of the quartz region. Migeotte has recently reported two fragmentary new systems.

 β SYSTEM

Occurrence. In discharge tubes containing oxygen and nitrogen and in the nitrogen afterglow, and especially strongly when excess of oxygen is introduced into active nitrogen. Weakly in absorption.

Appearance. Degraded to red. Double-headed. See Plate 3.

Transition. B $^2\Pi \rightarrow$ X $^2\Pi$, ground state.

References. R. C. Johnson and H. G. Jenkins, *Phil. Mag.*, **2**, 621. (1926).

F. A. Jenkins, H. A. Barton and R. S. Mulliken, *P.R.*, **30**, 150. (1927)†.

A. G. Gaydon, *Proc. Phys. Soc.*, **56**, 160. (1944)†.

The wave-lengths of the R heads of both sub-bands are given. The strong bands are from Jenkins, Barton and Mulliken's measurements, others by Johnson and Jenkins, and Gaydon.

λ	I	v', v''	λ	I	v', v''	I	λ	v', v''
5270.1	0	3, 18	4810.0	1	2, 16	4496.2	3	2, 15
5252.7			4791.4			4479.8		
4912.1	2	3, 17	4590.8	5	3, 16	4401.5	2	1, 14
4892.1			4574.0			4385.7		

INDIVIDUAL BAND SYSTEMS

NO (contd.)

λ	<i>I</i>	<i>v', v''</i>	λ	<i>I</i>	<i>v', v''</i>	λ	<i>I</i>	<i>v', v''</i>
4309.7	3	0, 13	3206.9	10	0, 8	2542.3	3	3, 5
4293.7			3198.0			2536.3		
4303.1	3	3, 15	3168.3	3	2, 9	2528.7	1	5, 6
4288.2			3159.8			2523.6		
4215.2	4	2, 14	3131.1	2	4, 10	2493.4	7	2, 4
4200.7			3125.0			2487.8		
4127.9	4	1, 13	3043.0	10	0, 7	2433.0	7	3, 4
4113.6			3034.9			2427.8		
4041.8	6	0, 12	3010.7	1	2, 8	2386.4	1	2, 3
4027.8			3002.8			2381.5		
3962.7	2	2, 13	2950.8	3	1, 7	2376.2	1	4, 4
3949.8			2943.2			2371.6		
3880.7	5	1, 12	2923.1	4	3, 8	2331.4	3	3, 3
3868.3			2915.9			2326.6		
3800.9	10	0, 11	2892.6	10	0, 6	2287.6	2	2, 2
3788.5			2885.2			—		
3658.5	4	1, 11	2809.4	4	1, 6	2236.1	6	3, 2
3647.2			2802.6			2232.0		
3583.5	10	0, 10	2786.0	3		2229.8	2	5, 3
3572.4			2779.5			—		
3456.9	2	1, 10	2754.3	9	0, 5	2183.2	0	6, 3
3446.0			2747.6			2179.2		
3408.5	1	3, 11	2731.7	1	2, 6	—	3	3, 1
3398.9			2725.4			2143.5		
3386.4	10	0, 9	2678.7	7	1, 5	2142.8	3	5, 2
3376.4			2672.2			2139.1		
3364.3	0		2626.6	6	0, 4	2103.6	2	4, 1
3355.2			2620.5			2099.8		
3340.3	3	2, 10	2608.3	6	2, 5	—	1	6, 2
3330.7			2602.1			2096.4		
3298.6	0	4, 11	2557.9	5	1, 4	2021.1	0	6, 1
3289.7			2551.8			2018.1		

I.M.S.

NO (contd.)

 δ SYSTEM

Occurrence. In active nitrogen and in condensed discharge through air. Also strongly in absorption.

Appearance. A single progression of double double-headed bands, degraded to shorter wave-lengths.

Transition. $C\ ^2\Sigma \rightarrow ^2\Pi$, ground state.

References. H. P. Knauss, *P.R.*, **32**, 417. (1928).

R. Schmid, *Z.P.*, **64**, 279. (1930)†.

A. G. Gaydon, *Proc. Phys. Soc.*, **56**, 160. (1944)†.

The following are the $^0P_{12}$ and P_2 heads, some from unpublished data by Gaydon:—

λ	I	v', v''	λ	I	v', v''
2414.6	1	0, 6	2060.9	4	0, 2
2407.6			2055.9		
2317.7	3	0, 5	1985.4	3	0, 1
2311.4			1980.5		
2226.8	4	0, 4	1914.2	2	0, 0
2220.8			1909.8		
2141.3	5	0, 3			
2135.8					

 ϵ SYSTEM

The bands of this system have at times been confused with those of the γ system, but this is now recognised as a separate system.

Occurrence. In discharge tubes containing nitrogen and air. Strongly in absorption. The strongest bands of this system lie in the vacuum ultra-violet, and only a few of the weaker bands are recorded with quartz instruments.

Appearance. Double double-headed bands degraded to shorter wave-lengths.

Transition. $D\ ^2\Sigma^+ \rightarrow ^2\Pi$, ground state.

References. M. Guillery, *Z.P.*, **42**, 121. (1927).

M. Hellermann, *Z.P.*, **104**, 417. (1936).

A. G. Gaydon, *Proc. Phys. Soc.*, **56**, 95 and 160. (1944)†.

The following are the $^0P_{12}$ and P_2 heads of bands in the quartz region:—

λ	I	v', v''	λ	I	v', v''
2181.8	3	0, 4	2022.3	3	0, 2
2176.1			2017.5		
2157.5	0	1, 5	2003.6	1	1, 3
—			1998.6		
2099.8	3	0, 3	1949.7	4	0, 1
2094.5			1945.0		
2078.2	3	1, 4			
2073.0					

NO (*contd.*)

MIGEOTTE'S SYSTEMS

Occurrence. Hollow cathode discharge.

Appearance. Degraded to red. Double-headed.

Reference. P. Migeotte, *Bull. Soc. Roy. Sci. Liège*, p. 40. (1945).

These bands are similar in appearance to the β bands, and in some cases appear to coincide with bands of this system. Migeotte has made a tentative analysis into two systems involving the ground state of NO.

1st System		2nd System	
λ	v', v''	λ	v', v''
2743	0, 2	2664	0, 2
2735		2657	
2611	0, 1	2424	0, 0
2604		2417	
2496	1, 1	2328	1, 0
2490		2322	
2384	1, 0		
2378			

Note added in Proof.

Y. Tanaka and M. Ogawa (*J. Sci. Research Institute, Japan*, 44, No 1208 (1949)†) has used a transformer discharge through flowing NO at relatively high pressure (a few mm. Hg) and observed a number of bands degraded to the violet. They have previously been reported by Grillet and others and are probably due to NO, but the assignment to transitions between very highly excited states of NO seems improbable to us. Most of the bands have four heads, of which the second may be the strongest.

λ	λ	λ	λ	λ	λ
6429.4	6324.1	6213.2	5907.4	5571.4	5242.5
6418.4	6316.0	6206.1	5900.0*	5564.5	5236.9
6403.7	6308.3	6196.7	5893.8	5558.6	5232.2
6398.1	6302.5	6192.3	5887.4	5551.3	—
6378.8	—	5940.6	5856.2	5534.3	
6369.6*	6267.3	5933.3*	5850.2	5528.2*	
6362.3	6258.8	5927.7	—	5522.6	
6355.2	6251.0	5921.4	5837.7	5517.7	

* Relatively strong in published photo.

NO⁺

Occurrence. In discharge tubes containing flowing NO or NO₂.

References. M. Duffieux and L. Grillet, *C.R. Acad. Sci. Paris*, 202, 937. (1936).

C. Jausseran, L. Grillet and M. Duffieux, *C.R. Acad. Sci. Paris*, 205, 39. (1937).

 $\lambda 5999$

Symmetrical band with P and R branches. Q branch weak or absent. Under very high dispersion the lines of the P and R branches are observed to be triple. Origin at 5998.9 A.

N₂O

References. A. K. Dutta, *P.R.S.*, **138**, 84. (1932).

H. Sponer and L. G. Bonner, *J. Chem. Phys.*, **8**, 33. (1940).

Nitrous oxide shows strong continuous absorption in the far ultra-violet, commencing near 2400 Å. Very weak continuous absorption has been observed to longer wave-lengths, as far as 3065 Å.

NO₂

The spectrum of NO₂ has been observed almost exclusively in absorption. It is extremely complicated and very extensive. For descriptive purposes it may be divided into two regions here referred to as the Visible and Ultra-violet Systems respectively.

THE VISIBLE SYSTEM

Occurrence. Readily obtained in absorption from NO₂ vapour. To obtain the spectrum in a pure state the temperature should be chosen so that N₂O₄ is decomposed but NO₂ is still stable (about 120° C.).

Appearance. With small amounts of gas a number of bands are obtained in the violet and ultra-violet regions, showing sharp rotational structure at the violet end but becoming more and more diffuse toward the ultra-violet and finally merging into a continuum. As the quantity of gas is increased the absorption spreads step by step to the red and sharp bands may be followed down to about 9000 Å. It is possible that more than one electronic system is involved. See Plate 8.

References. V. Henri, "The Structure of Molecules," p. 131. Edited by P. Debye. (1932).

L. Harris and R. W. B. Pearse, unpublished data.

Individual bands vary greatly in appearance. The following are some of the more outstanding edges and maxima :—

λ	I	λ	I	λ	I	λ	I
5095 M	3	4795 M	3	4545 R	4	4304 R	5
5048 M	3	4740 R	5	4480 M	10	4270 R	5
5027 M	3	4630 R	6	4448 R	8	4133 M	5
4945 M	3	4605 M	3	4390 R	8	4102 M	4
4880 R	3	4580 M	4	4350 M	6	4081 R	3

These are followed by many bands growing wider and more diffuse to about 3200 Å.

THE ULTRA-VIOLET SYSTEM

Occurrence. Obtained readily in absorption under the same conditions as the system in the visible.

Appearance. With a small quantity of gas two bands have sharp heads degraded to the red and show a very open rotational structure resembling a single Q branch. Other bands have been observed as far as 2000 Å. but are all diffuse. With a greater quantity of gas other sharp bands to the red are observed.

References. As for Visible System.

L. Harris, G. W. King, W. S. Benedict and R. W. B. Pearse, *J. Chem. Phys.*, **8**, 765. (1940).

NO₂ (contd.)

The strongest bands are as follows :—

λ	<i>I</i>		λ	<i>I</i>	
2491.4 R	6	sharp	2390 R	8	diffuse
2459.3 R	5	sharp	2372 R	8	very wide
2446.7 R	5	diffuse	2363 M	4	diffuse
2430 R	2	diffuse	2351 M	9	diffuse
2419 R	10	diffuse			

Further diffuse bands to 2000 A.

NS

There are two systems similar to the β and γ systems of NO. They have thus been designated as β and γ by Fowler and Bakker. See Plate 6.

 β SYSTEM

Occurrence. In discharge through nitrogen mixed with sulphur vapour.

Appearance. Pairs of bands degraded to red.

Transition. Probably ${}^2\Pi \rightarrow {}^2\Pi$, ground state.

Reference. A. Fowler and C. J. Bakker, *P.R.S.*, 136, 28. (1932)†.

The two sub-bands are indicated by i and ii.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
2697.4	5	1, 3 i	2540.1	2	2, 2 ii
2683.3	4	1, 3 ii	2518.5	8	0, 0 i
2680.0	4	0, 2 i	2506.7	8	0, 0 ii
2667.0	3	0, 2 ii	2477.8	3	2, 1 i
2614.6	4	1, 2 i	2465.6	3	2, 1 ii
2601.2	3	1, 2 ii	2460.7	7	1, 0 i
2597.1	6	0, 1 i	2448.7	6	1, 0 ii
2584.8	5	0, 1 ii	2406.0	4	2, 0 i
2553.1	3	2, 2 i	2394.4	4	2, 0 ii

 γ SYSTEM

Occurrence. In discharge through nitrogen mixed with sulphur vapour.

Appearance. Degraded to shorter wave-lengths. A single progression of double double-headed bands.

Transition. Probably ${}^2\Sigma \rightarrow {}^2\Pi$, ground state.

Reference. A. Fowler and C. J. Bakker, *P.R.S.*, 136, 28. (1932)†.

The two sub-bands are indicated by i and ii. Only the P heads are listed. The Q heads lie about 1.2 A. to the violet of these.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
2587.0	1	0, 4 ii	2383.6	10	0, 1 i
2525.7	3	0, 3 i	2371.1	10	0, 1 ii
2511.5	3	0, 3 ii	2317.2	10	0, 0 i
2453.0	5	0, 2 i	2305.2	8	0, 0 ii
2439.7	4	0, 2 ii			

Na_2

Band systems attributed to Na_2 have been observed in the red, in the blue-green, and in the ultra-violet.

RED SYSTEM

Occurrence. In absorption, in fluorescence, in magnetic rotation, and in emission in a discharge tube.

Appearance. Degraded to the red. Single-headed bands.

Transition. $^1\Sigma \rightarrow ^1\Sigma$, ground state.

Reference. W. R. Fredrickson and W. W. Watson, *P.R.*, **30**, 429. (1927).

The following are the strongest bands (listed as intensity 5) in absorption :—

λ	v', v''	λ	v', v''
6751.2	1, 2	6513.2	3, 0
6679.7	1, 1	6465.8	4, 0
6630.1	2, 1	6418.4	5, 0
6561.5	2, 0	6374.2	6, 0

BLUE-GREEN SYSTEM

Occurrence. Similar to red system and also in flame of metal burning in air.

Appearance. Degraded to the red.

Transition. $^1\Pi \rightarrow ^1\Sigma$, ground state.

References. W. R. Fredrickson and W. W. Watson, *P.R.*, **30**, 429. (1927).

F. W. Loomis and R. W. Wood, *P.R.*, **32**, 223. (1928).

The intensities as listed in the above references do not agree very well, but the following include the strong bands as observed in absorption :—

λ	v', v''	λ	v', v''
5040.4	0, 3	4894.5	1, 0
5001.4	0, 2	4865.5	2, 0
4962.8	0, 1	4837.2	3, 0
4932.6	1, 1	4819.5	5, 1
4924.2	0, 0	4809.8	4, 0

ULTRA-VIOLET SYSTEMS

References. J. M. Walter and S. Barratt, *P.R.S.*, **119**, 257. (1928).

W. Weizel and M. Kulp, *Ann. Phys. Lpz.*, **4**, 971. (1930).

M. Kimura and Y. Uchida, *Sci. Pap. Inst. Phys. Chem. Res. Tokyo*, **18**, 109. (1932).

S. P. Sinha, *Proc. Phys. Soc.*, **59**, 610. (1947).

S. P. Sinha, *Proc. Phys. Soc.*, **62**, 124. (1949).

Sodium vapour gives numerous bands in absorption in the region $\lambda\lambda 3640-2400$. Some of the bands have also been obtained in emission. The bands are degraded to the red and originate in transitions involving the $^1\Sigma$ ground state. Different arrangements of the bands into systems have been given by various authors. Sinha (1947) finds seven different systems of which only three are well developed. In the later paper Sinha investigates the strongest system in the region $\lambda\lambda 3600-3200$ with high dispersion. The data for the strongest bands are given below :—

Na₂ (*contd.*)

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3486.3	4	2, 6	3403.8	5	0, 0	3338.8	10	5, 0
3468.1	5	2, 5	3400.4	8	3, 2	3326.3	10	6, 0
3450.0	7	2, 4	3382.4	6	3, 1	3314.0	10	7, 0
3432.2	7	2, 3	3369.2	10	4, 1	3290.0	9	9, 0
3414.0	5	2, 2	3356.5	8	5, 1	3278.4	8	10, 0
3409.4	4	1, 1	3351.5	7	4, 0	3266.8	7	11, 0

The $\lambda 3303$ line of Na overlaps the system at the position of the (8, 0) band.

NaCd

Diffuse bands, degraded to the violet, observed in absorption by Barratt (see CsCd). Heads $\lambda\lambda 4000$ and 3974 .

NaCs

References. See LiCs.

Absorption bands observed by Walter and Barratt, and arranged into three systems by Weizel and Kulp. Degraded to the red. Strongest heads (intensity 10): $\lambda\lambda 5631, 5602, 5571, 5542, 5492, 5463, 5444, 5425, 4136, 4098$.

NaH

References. T. Hori, *Z.P.*, **62**, 352. (1930).
 T. Hori, *Z.P.*, **71**, 478. (1931).
 E. Olsson, *Z.P.*, **93**, 206. (1934).
 R. C. Pankhurst, *Proc. Phys. Soc.*, **62**, 191. (1949).

4500 A. SYSTEM, $^1\Sigma \rightarrow ^1\Sigma$, ground state

A many-lined system with weak R heads degraded to the red. The system is readily obtained in absorption from a mixture of hydrogen and sodium vapour and in emission from a sodium arc in hydrogen or a discharge through a mixture of hydrogen and sodium vapour, and in flames. See Plate 5.

v', v''	λ	Origins of the Strongest Bands		λ	<i>I</i>
		<i>I</i>	v', v''		
5, 1	4376.5	4	7, 0	4049.5	7
6, 1	4309.7	5	8, 0	3991.5	9
7, 1	4244.3	5	9, 0	3934.9	10
4, 0	4231.4	0	10, 0	3879.9	10
8, 1	4180.6	4	11, 0	3826.5	9
5, 0	4169.7	2	12, 0	3774.8	9
6, 0	4109.0	5	13, 0	3724.9	9

NaHg

Diffuse bands, degraded to the violet, observed in absorption by Barratt (see CsCd). Heads $\lambda\lambda 6499, 6454, 4649, 4425$ and 4406 .

NaI

The heated vapour shows strong continuous absorption in the near ultra-violet, merging into diffuse banded structure in the violet.

Reference. K. Sommermeyer, *Z.P.*, **56**, 548. (1929).

NaK

Four systems, in the near infra-red, the yellow, the green and the violet respectively, have been attributed to NaK.

Occurrence. All four systems have been observed in absorption by a mixture of sodium and potassium vapours. The yellow and green systems have also been observed in magnetic rotation, and the latter has been obtained in fluorescence.

Appearance. All the systems are degraded to longer wave-lengths.

INFRA-RED SYSTEM

Transition. B $^1\Sigma \leftarrow$ A $^1\Sigma$, ground state.

Reference. F. W. Loomis and M. J. Arvin, *P.R.*, **46**, 286. (1934).

Bands 9100–7200 Å. Strongest head: λ 8338 (3, 3).

YELLOW SYSTEM, λ 5970–5650

Transition. C $^1\Pi \leftarrow$ A $^1\Sigma$, ground state.

References. F. W. Loomis and M. J. Arvin, *P.R.*, **46**, 286. (1934).

S. Barratt, *P.R.S.*, **105**, 221. (1923–4)†.

S. P. Sinha, *Proc. Phys. Soc.*, **60**, 447. (1948)†.

Measurements, intensities in absorption and vibrational assignments given by Sinha :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
6066.2	3	0, 4	5869.5	5	1, 0	5711.7	9	9, 0
6040.5	2	1, 4	5845.2	7	2, 0	5696.2	8	10, 0
6022.1	2	0, 3	5823.5	6	3, 0	5680.8	8	11, 0
5997.0	3	1, 3	5802.6	7	4, 0	5676.0	3	13, 2
5973.0	2	2, 3	5783.0	6	5, 0	5665.3	6	12, 0
5954.2	3	1, 2	5763.4	7	6, 0	5650.4	5	13, 0
5935.1	3	0, 1	5745.4	9	7, 0	5640.8	4	14, 0
5912.0	4	1, 1	5728.2	10	8, 0			

GREEN SYSTEM, λ 5260–4730

Transition. C' $^1\Pi \leftarrow$ A $^1\Sigma$, ground state.

References. F. W. Loomis and M. J. Arvin, *P.R.*, **46**, 286. (1934).

S. P. Sinha, *Proc. Phys. Soc.*, **60**, 447. (1948)†.

Bands observed by Sinha :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
5261.8	1	0, 9	5011.9	5	3, 3	4836.5	8	11, 2
5230.5	1	0, 8	5001.8	6	2, 2	4830.3	10	8, 0
5198.9	1	0, 7	4982.2	7	3, 2	4819.3	7	12, 2
5167.5	2	0, 6	4962.4	7	4, 2	4813.0	8	9, 0
5136.3	3	0, 5	4943.2	5	5, 2	4796.2	7	10, 0
5115.0	2	1, 5	4932.2	8	4, 1	4779.7	6	11, 0
5105.4	3	0, 4	4913.5	8	5, 1	4764.1	5	12, 0
5083.8	4	1, 4	4894.5	8	6, 1	4748.5	4	13, 0
5063.5	3	2, 4	4876.8	10	7, 1	4733.1	4	14, 0
5052.6	4	1, 3	4866.0	8	6, 0	4717.8	4	15, 0
5032.4	4	2, 3	4847.4	10	7, 0	4702.7	4	16, 0

NaK (contd.)**ULTRA-VIOLET BANDS**

References. J. M. Walter and S. Barratt, *P.R.S.*, **119**, 257. (1928).

Y. Uchida, *Japan J. Phys.*, **5**, 145. (1929).

W. Weizel and M. Kulp, *Ann. Phys. Lpz.*, **4**, 971. (1930).

S. P. Sinha, *Proc. Phys. Soc.*, **60**, 447. (1948).

Sinha has measured eighty-nine bands in the region $\lambda\lambda 4080-3820$. Strongest bands :—

λ	<i>I</i>	λ	<i>I</i>	λ	<i>I</i>
3959.9	6	3898.4	6	3885.8	8
3954.9	6	3894.3	8	3880.1	6
3907.9	10	3888.6	8	3876.2	8

Walters and Barratt also obtained bands in the region $\lambda\lambda 3650-3550$. These were not obtained by Sinha, who suggests that they belong to Na_2 .

NaRb

Bands, degraded to the red, have been observed in absorption by a mixture of sodium and rubidium vapours.

References. See LiCs.

Strongest bands : $\lambda\lambda 5432, 5397, 5368, 5339, 5331$.

NdO

Occurrence. Neodymium salts in oxy-hydrogen flame.

Reference. G. Piccardi, *Rend. Accad. Linc.*, **21**, 584. (1935).

The following are among the strongest of over 250 heads listed :—

λ	<i>I</i>	λ	<i>I</i>	λ	<i>I</i>	λ	<i>I</i>
6629.6	8	6585.2	15	5999	8	5250.2	6
6624.6	8	6370.9	8	5996	8	4768.7	4
6620.2	7	6368.6	8	5990.7	10	4620.0	8
6606.7	10	6353.5	9	5975	10	4510.8	3
6602.4	10	6249.9	10	5971.1	8	4413.5	3
6598.3	10	6002	8	5313.5	7		

Ne₂ ?

Reference. D. G. Dhavale, *Nature, Lond.*, **125**, 276. (1930).

Headless bands at $\lambda\lambda 7393, 7208, 7063, 6963$ and 6847 with rather open rotational structure, may be due to Ne_2 . They were obtained in a transformer discharge.

NiBr or NiBr₂

Occurrence. In high-frequency discharge through nickel bromide vapour.

Reference. P. Mesnage, *Thesis for doctorate, Paris.* (1938).

The bands are degraded to longer wave-lengths. There is a strong system with (0, 0) band at $\lambda 4590.2$ and other fragmentary analyses are proposed by Mesnage.

Strongest bands :—

NiBr or NiBr₂ (contd.)

λ	I	λ	I	λ	I
4744.0	4	4598.3	7	4257.7	4
4669.0	5	4590.2	10	4231.4	4
4664.6	4	4554.8	4	4037.4	5
4659.6	5	4541.6	4	3988.0	4
4637.2	4	4456.3	5	3930.1	5
4604.5	6	4354.3	4		

NiCl

References. P. Mesnage, *C.R. Acad. Sci. Paris*, **200**, 2072 (1935) and *Thesis for doctorate, Paris*. (1938).

K. R. More, *P.R.*, **54**, 122. (1938).

A number of bands have been observed in a high-frequency discharge. These are degraded to the red and fall into a number of well-marked sequences. More has analysed some of them into four systems. The following are probably the outstanding heads, mostly heads of sequences from Mesnage :—

λ	System	v', v''	λ	System	v', v''
5352.2			4216.0	3	1, 0
5013.2*			4131.1	4	0, 1
4705.5			4143.1*	3	0, 0
4620.0			4094.2*		
4562.7			4081.4		
4485.1			4061.5*	4	0, 0
4396.6	1	0, 0	3996.9	4	1, 0
4304.9*	2	0, 0			

* Relatively strong.

More has analysed most of the bands around 4400–4000 into four systems (probably due to a transition between two quartet states) with heads of (0, 0) sequences at $\lambda\lambda$ 4396.6, 4304.9, 4143.1, 4061.5.

NiH

References. A. G. Gaydon and R. W. B. Pearse, *P.R.S.*, **148**, 312. (1935)†.
A. Heimer, *Z.P.*, **105**, 56. (1936)†.

6442 A. SYSTEM, ${}^2A_{2\frac{1}{2}} \rightarrow {}^2A_{2\frac{1}{2}}$

Band showing widely-spaced R and P branches with narrow doublets. A Q branch is observed near the origin but quickly decreases in intensity with increasing rotation. Occurs in flames fed with nickel carbonyl, in high-tension arcs in hydrogen flame, and in discharges where hydrogen and nickel vapour are present together.

v', v''	Heads		I
	R	Q	
0, 0	6425.1	6443.3	4

NiH (*contd.*)6257 A. SYSTEM, ${}^2A_{2\frac{1}{2}} \rightarrow {}^2A_{2\frac{1}{2}}$

Bands similar in appearance to the above system and occurring under similar conditions. See Plate 5.

v', v''	Heads		
	R	Q	I
0, 0	6246.0	6260.1	10
1, 0	5712.5	5724.8	7
2, 0	5290.0	5300.5	2
3, 0	4952.1	4962.0	1

4207 A. SYSTEM, ${}^2A_{2\frac{1}{2}} \rightarrow {}^2A_{2\frac{1}{2}}$

Bands similar in appearance and occurrence to those of the other two systems.

v', v''	Heads	
	R	Q
0, 1	4570.5	4579.5
0, 0	4200.6	4208.3

There is also much weak unsystematised band-structure in the orange and red; there are weak heads (deg. R) at $\lambda\lambda 6391.8, 6171.5$ and 5834.3 .

NiO

Three strong sequences in the infra-red and numerous bands in the visible have been observed in a nickel arc in air, in a flame containing nickel carbonyl, and in exploding wires. They have mostly been arranged by Malet and Rosen into six systems.

References. L. Malet and B. Rosen, *Bull. Soc. roy. Sci. Liège*, 382. (1945).

B. Rosen, *Nature, Lond.*, 156, 570. (1945).

In the following tables wave-lengths given to 0.1 A. are by Gaydon; others by Malet and Rosen, whose values often differ from Gaydon's by several A. All bands are degraded to greater wave-lengths.

SYSTEM I. INFRA-RED.

7900 (0, 0), 7983 (1, 1), 8094 (2, 2), 8187 (3, 3), 8300 (0, 1), 8392 (1, 2), 8502 (2, 3), 8600 (3, 4), 8739 (0, 2), 8843 (1, 3), 8950 (2, 4), 9070 (3, 5), 9195 (4, 6).

SYSTEM II. RED.

7611 (0, 1), 7404 (1, 1), 7330 (0, 0), 7122 (2, 1), 7090 (1, 0).

SYSTEM III.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
6604.5	1	1, 3	6325	1	0, 1	5935.5	2	3, 2
6581	1	0, 2	6152.1	5	3, 3	5914.1	5	2, 1
6385.8	5	3, 4	6133.3	8	2, 2	5703	3	2, 0
6368	1	2, 3	6111	1	1, 1	5529.5	8	3, 0
6342.2	8	1, 2						

NiO (*contd.*)

SYSTEM IV.

λ	I	v', v''
5407.7	5	0, 1
5174.5	10	0, 0
5024	4?	1, 0
4889.5	5	2, 0

SYSTEM V.

λ	I	v', v''
5323.4	2	0, 1
5098.3	3	0, 0
4951	0	1, 0

SYSTEM VI.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
4849.2	2	2, 2	4606.5	2	1, 0	4382	2	3, 0
4790.1	1	1, 1	4545.6	2	3, 1	4334	1	5, 1
4730	2?	0, 0	4494.3	1	2, 0	4238	0	6, 1
4721.4	1	3, 2	4436	2	4, 1	4145	0	7, 1
4665.7	5	2, 1						

Unclassified bands, $\lambda\lambda$ 6704, 6537, 6460, 6264, 6038, 5454.9, 5006.6 (5), 4938.8, 4876.7 (5), 4751.0 (8), 4714.6, 4630, 4405.

O₂

The neutral oxygen molecule does not readily show an emission spectrum in discharge tubes at low pressure. A part of the main absorption system observed by Schumann has been observed in emission by Runge, and Hopfield has reported an emission spectrum in the region below 2218 Å. There are several weak absorption systems, including the atmospheric absorption bands and Herzberg's system. The absorption spectrum of liquid oxygen is also described briefly.

SCHUMANN-RUNGE SYSTEM

Occurrence. The main part of this system lies in the vacuum ultra-violet below 1900 Å. Using heated gas and greater thicknesses, band structure may be extended well into the quartz region. The bands may sometimes be observed as an impurity in absorption using furnaces in which a considerable path of air becomes heated. Runge, and later Feast, have observed the longer wave-length end of the system in emission from a high tension arc in oxygen at around atmospheric pressure; it does not appear at low pressure. Recently the bands have been obtained in emission from CO-O₂ and H₂-O₂ flames (G. A. Hornbeck, *J. Chem. Phys.*, **16**, 845 and 1005 (1948); H. G. Wolfhard and A. G. Gaydon, *Nature, Lond.*, **164**, 22. (1949)).

Appearance. Degraded to longer wave-lengths. Relatively open rotational structure. See Plates 7 and 8.

Transition. B ³Σ → X ³Σ, ground state.

References. S. W. Leifson, *Astrophys. J.*, **63**, 73. (1926)†.

W. Jevons, *Report on Band Spectra of Diatomic Molecules*, The Physical Society. (1932).

O_2 (contd.)

- H. P. Knauss and S. S. Ballard, *P.R.*, **48**, 796. (1935)†.
 C. Füchtbauer and E. Holm, *Phys. Zeit.*, **26**, 345. (1925).
 W. Lochte-Holtgreven and G. H. Dieke, *Ann. Phys. Lpz.*, **3**, 937.
 (1929).
 M. W. Feast, *Proc. Phys. Soc.*, **A62**, 114, (1949)† and **A63**, 549.
 (1950).

Absorption. Absorption by oxygen sets the limit to work with quartz spectrographs in air, and the bands are often seen at the end of spectra taken with small quartz instruments. The strong bands lie below 1900 Å., and merge into continuous absorption beyond 1759 Å. In the following table the wave-lengths are given in air; for vacuo it is necessary to add about 0.6 Å. Intensities are rough estimates from Leifson's and Knauss and Ballard's photographs and published descriptions for absorption at atmospheric temperature. The bands with $v'' = 1$ are stronger in heated oxygen, and bands with higher v'' are only observed with the heated gas. With strongly heated oxygen absorption may be observed as far as 2500 Å., but in this region it consists only of complex line structure and definite heads are not observed.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
2221.0	—	5, 5	2017.3	—	8, 3	1863.0	10	7, 0
2193.4	—	6, 5	1997.5	0	1, 0	1845.8	10	8, 0
2167.9	—	7, 5	1971.4	1	2, 0	1830.1	10	9, 0
2150.8	—	5, 4	1959.5	0	5, 1	1815.6	10	10, 0
2125.0	—	6, 4	1946.7	2	3, 0	1803.1	10	11, 0
2101.1	—	7, 4	1938.0	0	6, 1	1792.0	9	12, 0
2084.2	—	5, 3	1923.5	4	4, 0	1782.3	7	13, 0
2079.7	—	8, 4	1918.3	1	7, 1	1774.3	6	14, 0
2060.0	—	6, 3	1901.9	6	5, 0	1767.7	4	15, 0
2037.6	—	7, 3	1900.1	1	8, 1			
2020.7	—	5, 2	1881.7	8	6, 0			

Emission. The following measurements of the emission bands observed by Runge are by Lochte-Holtgreven and Dieke; the values are for the origins of the bands, but as these are so strongly degraded, the origins are less than 0.5 Å. from the heads, which are of course to the shorter wave-length side. The intensities are on a scale of 6 based on the intensities of individual lines.

λ_0	I	v', v''	λ_0	I	v', v''	λ_0	I	v', v''
4372.6	5	2, 21	3987.3	4	2, 19	3516.6	5	0, 15
4292.4	5	1, 20	3912.8	5	1, 18	3500.0	2	2, 16
4214.7	5	0, 19	3841.1	6	0, 17	3370.1	5	0, 14
4173.2	6?	2, 20	3742.2	5	1, 17	3356.8	3	2, 15
4095.9	6	1, 19	3673.2	5	0, 16	3232.9	4	0, 13
4021.1	5	0, 18	3583.0	3	1, 16	3104.3	4	0, 12

Feast has photographed the emission spectrum over the range 5000–2000 Å and has extended the vibrational and rotational analysis. He finds the intensity of the system to be very pressure dependent.

O_2 (contd.)

HOPFIELD'S EMISSION SYSTEM

Occurrence. Condensed discharge through oxygen and helium.

Appearance. Degraded to shorter wave-lengths. One progression.

Reference. J. J. Hopfield, *P.R.*, **36**, 789. (1930).

The following are the bands observed: $\lambda\lambda 2217.5, 2170.0, 2123.1, 2076.6, 2030.8$.

The bands may be a v' progression with the 2031 band as the (0, 0).

ATMOSPHERIC ABSORPTION

Occurrence. In atmospheric absorption (especially solar spectrum). The bands have also been observed in the laboratory by absorption through pure oxygen.

Appearance. The bands are degraded to longer wave-lengths, but the heads are in some cases weak.

Transition. $A\ ^1\Sigma_g^+ \leftarrow X\ ^3\Sigma_g^-$, ground state; forbidden.

References. G. H. Dieke and H. D. Babcock, *Proc. Nat. Acad. Sci., U.S.A.*, **13**, 670. (1927).

W. Ossenbruggen, *Z.P.*, **49**, 167. (1928).

R. Mecke and W. Baumann, *Z.P.*, **73**, 139. (1932).

The following measurements are compiled from the above. Intensities are our own estimates based on the references.

λ Head	λ Origin (approx.)	I	v', v''
7685	7708	2?	1, 1
7593.7	7620	10	0, 0
6867.2	6883	8	1, 0
6276.6	6287	3	2, 0
5788.1	5796	1	3, 0
5380	—	0	4, 0

These bands have recently been obtained in *emission* from CO- O_2 explosion flames (R. C. Herman, G. A. Hornbeck and S. Silverman, *J. Chem. Phys.*, **17**, 220. (1949)†; G. A. Hornbeck and H. S. Hopfield, *J. Chem. Phys.*, **17**, 982. (1949)). The following additional heads are reported; 8803 (2, 3), 8697.8 (1, 2), 8597.8 (0, 1), 7879.2 (3, 3) and 7779.0 (2, 2).

HERZBERG ABSORPTION BANDS

Occurrence. In absorption. Herzberg used 25 metres of oxygen at 1 atm. Probably in emission in the night sky.

Appearance. Single Q branches degraded to the red. The rotational structure is relatively open.

Transition. $^3\Sigma_u^+ \leftarrow X\ ^3\Sigma_g^-$, ground state; forbidden.

Reference. G. Herzberg, *Naturwiss.*, **20**, 577. (1932).

Herzberg assumes the bands are the $v'' = 0$ progression and gives the following wave-lengths of the origins: $\lambda\lambda 2595, 2554.0, 2519.1, 2488.5, 2463.0, 2442.8, 2429.0$.

HIGH PRESSURE BANDS

Occurrence. In absorption at high pressure. They may be due to O_4 .

Appearance. Headless bands, degraded to the red. Under small dispersion the bands appear to have triple maxima, the centre one being strongest. See Plate 8.

Reference. W. Finkelberg and W. Steiner, *Z.P.*, **79**, 69. (1932)†.

O_2 (*contd.*)

Finkelnberg and Steiner give the following groups. No intensities are available, but the bands to shorter wave-lengths appear at lower pressures (*i.e.*, are the strongest).

λ	λ	λ	λ
—	2510	2625	2775
2440	2518	2632	2784
—	2525	2642	2796
2458	2543	2672	2832–2859
2465	2553	2678	
2473	2561	2690	
2481	2583	2721	
2489	2591	2730	
2497	2600	2740	

LIQUID ABSORPTION

Occurrence. Absorption by liquid oxygen.

Appearance. Degraded to longer wave-lengths.

Reference. J. C. McLennan, H. D. Smith and J. O. Wilhelm, *Trans. Roy. Soc. Canada*, iii, 24, 65. (1930)†.

The following measurements represent the limits of the bands; most of the bands have fairly sharp heads and the longer wave-length edge is the head. Intensities are our estimates from the published photographs. The bands have been analysed into several systems.

λ limits	I	λ limits	I	λ
10420–10220	?	4802–4710	3	2863
9300–9100	?	4628–4605	0	2800
8300–8200	?	4481–4456	2	2763
7665–7590	3	4208–4180	1	2735
6916–6875	0	3930–3920	0	2686
6368–6160	10	3825–3785	3	2639
5826–5640	9	3628–3585	3	continuous
5364–5290	4	3455–3423	?	absorption
4982–4916	1	3305–3274	?	below 2609

The bands in the visible region have also been observed in absorption by solid oxygen, with slight changes of wave-length and intensity.

 O_2^+

There are two easily obtained systems of bands which are attributed to the ionised oxygen molecule, the First Negative oxygen bands from the red to the green, and the Second Negative in the ultra-violet.

FIRST NEGATIVE SYSTEM

Occurrence. In discharges through oxygen, especially at low pressure, in hollow cathodes, and in high frequency discharge.

O_2^+ (contd.)

Appearance. Degraded to the violet. Bands of complex structure. With small dispersion the appearance is of five strong bands somewhat similar in spacing and region to the Ångström, bands of CO. See Plate 7.

Transition. $^4\Sigma_g^- \rightarrow ^4\Pi_u$.

References. R. Frerichs, *Z.P.*, **35**, 683. (1926).

L. Bozoky and R. Schmid, *P.R.*, **48**, 465. (1935).

T. E. Nevin, *Phil. Trans. Roy. Soc.*, **A237**, 471. (1938)†.

N. L. Singh and L. Lal, *Sci. Cult.*, **9**, 89. (1943).

Wave-lengths of first heads from above references, with intensities from Singh and Lal.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
7891		0, 4	5883.4	8	3, 3	5295.7	9	2, 0
7348		0, 3	5847.3	2	4, 4	5274.7	10	3, 1
6856.3	(9)	0, 2	5814	1	5, 5	5259	6	4, 2
6418.7	10	0, 1	5631.9	10	1, 0	5251	10	5, 3
6351.0	10	1, 2	5597.5	10	2, 1	5241	8	6, 4
6026.4	10	0, 0	5566.6	6	3, 2	5234	9	7, 5
5973.4	10	1, 1	5540.7	2	4, 3	5005.6	2	3, 0
5925.6	9	2, 2	5521	2	5, 4	4998	2	4, 1
						4992	2	5, 2

SECOND NEGATIVE SYSTEM

Occurrence. In discharge tubes containing oxygen, especially in the negative glow, at low pressures, or in the presence of excess of helium. Also in high-frequency discharge.

Appearance. Degraded to the red. An extensive system of double-headed bands, separation about 200 cm^{-1} . See Plate 7.

Transition. $^2\Pi \rightarrow ^2\Pi$, lowest known state of ionised oxygen.

References. R. C. Johnson, *P.R.S.*, **105**, 683. (1923-24)†.

V. M. Ellsworth and J. J. Hopfield, *P.R.*, **29**, 79. (1927)†.

R. S. Mulliken and D. S. Stevens, *P.R.*, **44**, 720. (1933).

M. W. Feast, *Proc. Phys. Soc.*, **A63**, 557. (1950).

In the following table the bands with intensities are from Johnson's measurements; bands without recorded intensities are from the other references quoted above; they are relatively weak bands. The R_2 and R_1 heads are denoted by ii and i following the vibrational quantum numbers.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
6102.9		1, 14 ii	4399.4		0, 9 ii	3603.7	7	0, 6 i
5678.3		1, 13 i	4363.1		0, 9 i	3594.5	2	2, 7 i
5498.4		0, 12 ii	4115.8	8	0, 8 ii	3517.7	8	1, 6 ii
5443.0		0, 12 i	4082.4	8	0, 8 i	3494.2	7	1, 6 i
5086.3		0, 11 ii	3859.5	8	0, 7 ii	3421.2	8	0, 5 ii
5035.1		0, 11 i	3830.5	8	0, 7 i	3416.2	2	2, 6 ii
4877.6		1, 11 ii	3733.9	8	1, 7 ii	3397.8	8	0, 5 i
4820.3		1, 11 i	3706.6	8	1, 7 i	3393.1	4	2, 6 i
4720.7		0, 10 ii	3629.8	8	0, 6 ii	3322.6	6	1, 5 ii
4678.5		0, 10 i	3620.1	2	2, 7 ii	3300.3	6	1, 5 i

O_2^+ (contd.)

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
3231.2	8	2, 5 ii	2646.7	6	4, 2 ii	2307.2		9, 1 i
3210.8	8	2, 5 i	2632.7	6	4, 2 i	2291.8		7, 0 ii
3141.0	5	1, 4 ii	2594.3	8	5, 2 ii	2285.8		10, 1 ii
3123.1	5	1, 4 i	2581.0	8	5, 2 i	2281.3		7, 0 i
3062.8	8	2, 4 ii	2545.5	7	6, 2 ii	2275.3		10, 1 i
3043.6	8	2, 4 i	2532.8	6	6, 2 i	2252.8		11, 1 ii
2987.5	8	3, 4 ii	2512.9	3	4, 1 i	2246.9		8, 0 i
2970.0	7	3, 4 i	2500.6	6	7, 2 ii	2243.5		11, 1 i
2919.8	8	4, 4 ii	2488.3	6	7, 2 i	2224.3		9, 0 ii
2907.1	5	2, 3 ii	2478.0	4	5, 1 ii	2213.8		9, 0 i
2901.9	7	4, 4 i	2465.8	2	5, 1 i	2183.9		10, 0 i
2890.3	7	2, 3 i	2458.6	1	8, 2 ii	2164.0		11, 0 ii
2839.7	9	3, 3 ii	2446.9	1	8, 2 i	2155.3		11, 0 i
2823.7	8	3, 3 i	2433.5	3	6, 1 ii	2138.6		12, 0 ii
2776.7	7	4, 3 ii	2421.8	2	6, 1 i	2128.4		12, 0 i
2761.9	7	4, 3 i	2392.6	3	7, 1 ii	2112.2		13, 0 ii
2720.0	7	5, 3 ii	2381.0	3	7, 1 i	2103.7		13, 0 i
2705.3	7	5, 3 i	2354.3	1	8, 1 ii	2090.3		14, 0 ii
2688.5	2	3, 2 i	2343.3	1	8, 1 i	2080.8		14, 0 i
2666.5	4	6, 3 ii	2328.7		6, 0 ii	2068.3		15, 0 ii
2652.3	4	6, 3 i	2317.9		6, 0 i	2059.7		15, 0 i

Feast using high-frequency discharges in pure oxygen has found additional bands belonging to this system in the region 5200–2500 Å.

 O_3

ULTRA-VIOLET SYSTEM

Occurrence. These bands occur strongly in absorption by ozone; this absorption is responsible for the ultra-violet limit of solar radiation reaching the earth.

Appearance. The usual appearance of ozone absorption is a fairly sharp cut-off in the ultra-violet, between 3000 Å. and 3600 Å., according to the thickness of ozone, with a few narrow bands showing up clearly in the neighbourhood of this cut-off. The bands are headless, but in some cases appear slightly degraded to the red. The bands are clearest in the region 3200–3400 Å.; they extend to below 2500 Å., but are only faintly visible above the continuous absorption in most regions.

References. A. Fowler and R. J. Strutt, *P.R.S.*, **93**, 577. (1917)†.

O. R. Wulf and E. H. Melvin, *P.R.*, **38**, 330. (1931)†.

A. Jakowlewa and V. Kondratjew, *Phys. Zeit. Sowjetunion*, **1**, 471. (1932).

The following measurements are by Fowler and Strutt; these agree well with those of Jakowlewa and Kondratjew, whose measures are however lower by about 1 Å. The bands have been partly analysed by Wulf and Melvin and by Jakowlewa and Kondratjew.

O_3 (contd.)

λ	I	λ	I	λ	I	λ	I
3432.2	1	3311.5	5d	3227.2	10	3171.6	4
3421.4	1	3304.1	3	3221.5	10	3162.6	2d
3402.6	1	3284.0	2	3206.8	2	3156.1	8
3377.7	1	3279.8	8d	3201.0	8d	3137.4	10d
3374.1	3	3272.0	3	3194.8	6	3114.3	8d
3365.2	1	3255.5	5	3188.8	1	3105.0	5
3346.0	1	3249.7	8	3181.5	1	3096.5	4
3338.5	4	3243.0	1d	3177.0	8d	3089.5	8d
3331.2	1	3232.8	1				

d = diffuse.

Emission. A number of emission bands have been reported by J. Janin, *C. R. Acad. Sci., Paris*, **207**, 145 (1938) in the violet region.

Feast (see O_2^+) has identified bands attributed by Johnson to O_3 with bands of O_2^+ and lines of O^+ .

VISIBLE ABSORPTION BANDS

Wulf has observed absorption bands of ozone in the orange and in the infra-red, using long columns of the gas. There are two strong diffuse bands at about 5730 and 6020 A. The cut-off in the infra-red varies from around 9000 A. for short paths of ozone, up to the limit of the visible, and finally the absorption merges with the orange bands for very long paths.

Reference. O. R. Wulf, *Proc. Nat. Acad. Sci., U.S.A.*, **16**, 507. (1930)†.

 O_4

See O_2 High Pressure Bands.

OH

References. W. W. Watson, *Astrophys. J.*, **60**, 145. (1924)†.

L. Grebe and O. Holtz, *Ann. Physik.*, **39**, 1243. (1912).

D. Jack, *P.R.S.*, **115**, 373. (1927)†.

118, 647. (1928).

120, 222. (1928).

T. Tanaka and Z. Koana, *Proc. Phys. Math. Soc. Japan*, **15**, 272. (1933).

3064 A. SYSTEM, $^2\Sigma \rightarrow ^2\Pi$, GROUND STATE

Bands degraded to the red with four heads, two R and two Q. The most clearly defined is the higher frequency R head, the others being much overlapped. The system occurs in emission in almost all sources where water vapour is present, such as flames, arcs, and discharge tubes. May be obtained in absorption when conditions are such that sufficient concentration of free OH radicals is maintained. See Plate 4.

v', v''	$^8R_{21}$	R_2	R_1	Q_2	Q_1	I
3, 0	—	2444	—	—	—	0
2, 0	—	2608.5	2613.4	2613.4	2622.1	3
3, 1	—	2677.3	2683.1	2681.8	2691.1	2

OH (contd.)

v', v''	$^sR_{21}$	R_2	R_1	Q_2	Q_1	I
1, 0	—	2811.3	2816.0	2819.1	2829.0	6
2, 1	—	2875.3	2880.6	2882.3	2892.7	3
3, 2	—	2945.2	2951.2	2951.2	2962.4	1
0, 0	3021.2	3063.6	3067.2	3078	3089	10
1, 1	—	3121.7	3126.4	—	—	1
2, 2	—	3184.8	3190.2	3195.9	3208.7	1
0, 1	—	3428.1	3432.1	3458.5	3472.1	2

OH⁺

- References. F. W. Loomis and W. H. Brandt, *P.R.*, 49, 55. (1936)†.
W. H. Rodebush and M. H. Wahl, *J. Chem. Phys.*, 1, 696. (1933)†.

3565 A. SYSTEM, $^3\Pi \rightarrow ^3\Sigma$

Complex bands degraded to the red, each showing nine strong branches, three P, three Q, and three R.

Discovered by Rodebush and Wahl in an electrodeless discharge through water vapour. Obtained in a similar manner by Loomis and Brandt in a special D-shaped discharge tube.

v', v''	Heads	R
0, 1	3893	
1, 1	3695	
0, 0	3565	
1, 0	3332	

P₂

Only one band system has so far been definitely attributed to diatomic phosphorus.

Occurrence. In emission, especially in discharge tubes with hydrogen as a carrier of the discharge, in fluorescence and in absorption.

Appearance. Degraded to the red. This is a very extensive system of single-headed bands extending throughout the ultra-violet; the large number of bands of about equal intensity is a characteristic feature of the spectrum. See Plate 6.

Transition. $^1\Sigma \rightarrow ^1\Sigma$, ground state.

- References. A. Jakowlewa, *Z.P.*, 69, 548. (1931).
G. Herzberg, *Ann. Physik.*, 15, 677. (1932).
M. F. Ashley, *P.R.*, 44, 919. (1933)†.

Emission. The following measurements are from Herzberg:—

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
3222.9	4	11, 30	3069.5	5	6, 24	2774.5	4*	5, 18
3201.9	4	10, 29	3064.2	4	9, 26	2757.1	6*	4, 17
3184.1	4	9, 28	3046.4	4	8, 25	2707.4	4*	7, 18
3166.2	5	8, 27	3028.7	4	7, 24	2690.5	5	6, 17
3141.1	4	10, 28	2953.6	7	6, 22	2689.3	4*	3, 15
3123.3	5	9, 27	2898.0	4*	6, 21	2645.2	5	9, 18
3105.4	5	8, 26	2845.7	5	3, 18	2642.1	4	6, 16
3082.0	5	10, 27	2830	—*	5, 19	2628.1	5	8, 17

* These bands appear prominently on the reproduction by Ashley.

P_2 (contd.)

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
2625.5	5*	5, 15	2520.8	5	7, 14	2461.0	6	6, 12
2586.6	5	11, 18	2516.6	6	4, 12	2456.9	6	3, 10
2582.0	5	8, 16	2513.6	5	1, 10	2450.6	5	8, 13
2578.0	4	5, 14	2509.6	4	9, 15	2413.7	4	3, 9
2565.6	4	7, 15	2472.5	4	4, 11	2403.3	5	5, 10
2562.1	5	4, 13	2468.6	4	1, 9	2393.3	4	7, 11

* These bands appear prominently on the reproduction by Ashley.

Only bands listed by Herzberg as intensity 4 or greater are given above; this only represents a small fraction of the whole system.

Absorption. Strongest bands listed by Jakowiewa:—

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
2261.6	4	1, 4	2128.6	4	2, 1	2074.9	5	3, 0
2186.4	4	1, 2	2122.6	5	4, 5	2069.0	5	5, 1
2164.3	5	2, 3	2108.1	6	3, 1	2055.0	5	4, 0
2150.0	5	1, 1	2094.3	4	2, 0	2050.0	4	6, 1
2143.0	5	3, 4	2088.3	4	4, 1	2036.0	5	5, 0

PH

References. R. W. B. Pearse, *P.R.S.*, **129**, 328. (1930)†.

M. Ishaque and R. W. B. Pearse, *P.R.S.*, **173**, 265. (1939)†.

3400 A. SYSTEM, $^3\Pi_i \rightarrow ^3\Sigma$

Complex band obtained in emission from a discharge tube containing phosphorus vapour and hydrogen. See Plate 5.

v', v''	Heads λ (I)				
0, 0	3390.1 (5)	3394.9 (7)	3409.2 (4)	3419.6 (10)	3426.8 (5)

PN

Occurrence. In heavy-current discharge tubes containing phosphorus and nitrogen.

Appearance. Degraded to the red. Close double-headed bands (separation about 0.6 Å.). Well-marked sequences.

Transition. $^1\Pi \rightarrow ^1\Sigma$.

Reference. J. Curry, L. Herzberg and G. Herzberg, *Z.P.*, **86**, 348. (1933)†.

The following are the strong bands. The intensities have been reduced to a scale of 10. The R heads only are given here.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
2742.9	3	3, 5	2620.1	8	1, 2	2466.2	7	2, 1
2727.5	4	2, 4	2605.0	9	0, 1	2451.1	8	1, 0
2712.1	4	1, 3	2533.0	3	1, 1	2418.7	3	4, 2
2696.9	3	0, 2	2518.2	10	0, 0	2403.3	3	3, 1
2635.2	4	2, 3	2481.4	3	3, 2	2388.2	2	2, 0

PO

Two band systems in the ultra-violet have been attributed to PO. They correspond to the β and γ system of nitric oxide. Bands have also been observed in the visible by Geuter using flame and discharge tube sources; the emitting molecule is uncertain but may be PO.

 β SYSTEM $\lambda\lambda 3241-3587$

Occurrence. In arcs and discharge tubes containing phosphorus and oxygen, and in flames containing phosphorus oxychloride.

Appearance. There is a strong sequence of bands commencing at around 3240 Å. and getting weaker to longer wave-lengths; this sequence has no marked head and the bands of which it is formed show heads degraded in both directions. There are two similar weaker sequences further to the red.

Transition. This probably consists of two overlapping systems, system A, of bands degraded to the red, ${}^2\Sigma \rightarrow {}^2\Pi$, ground state, and system B of bands degraded to the violet due to ${}^2\Pi \rightarrow {}^2\Pi$, ground state.

References. P. Geuter, *Z. wiss. Photogr.*, **5**, 33. (1907).

A. Petrikaln, *Z.P.*, **51**, 395. (1928)†.

J. Curry, L. Herzberg and G. Herzberg, *Z.P.*, **86**, 364. (1933).

R. Ramanadham, G. V. S. R. Rao and C. Ramasastry, *Indian J. Phys.*, **29**, 161. (1946)†.

Curry, Herzberg and Herzberg gave a formula for an analysis into a ${}^2\Pi \rightarrow {}^2\Pi$ system, and since then Ramanadham *et al.* have proposed analysis into two systems. Their analysis is given here, with wave-lengths and intensities based largely on Geuter's. The letters R and V indicate direction of degradation of the head, and A and B the system to which the head is assigned. Only the strongest heads of this complex system are given here.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3460.1 R	2 A	1, 2 i?	3379.8 V	3 B	0, 1 ii	3280.7 R?	4 A	5, 4 i
3424.7 V	3 B	2, 3 i	3346.3 R	3 A	2, 2 i	3270.5 V	6 B	0, 0 i
3414.2 V	3 B	1, 2 i	3328.4 R	4 A	1, 1 i	3268.9 R	5 A	10, 8 ii?
3409.7 V	3 B	3, 4 ii	3321.0 R	3 A	2, 2 ii	3266.7 V	3 B	2, 2 ii
3405.8 V	3 B	0, 1 i	3311.9 R	5 A	0, 0 i	3255.3 V	6 B	1, 1 ii
3397.9 V	3 B	2, 3 ii	3296.4 R	5 A	10, 8 i?	3253.4 R	5 A	4, 3 ii
3388.0 V	3 B	1, 2 ii	3285.8 R	3 A	0, 0 i	3246.3 V	6 B	0, 0 ii

 γ SYSTEM, $\lambda\lambda 2750-2280$

Occurrence. Phosphorus compounds in carbon arc, in discharge tubes containing phosphorus and oxygen, and in flames.

Appearance. Degraded to shorter wave-lengths. The bands are double double-headed and the sequences are fairly well marked. See Plate 6.

Transition. A ${}^2\Sigma \rightarrow X {}^2\Pi$, ground state.

References. A. Petrikaln, *Z.P.*, **51**, 295. (1928)†.

P. N. Ghosh and G. N. Ball, *Z.P.*, **71**, 362. (1931)†.

The following measurements of the strong bands are by Ghosh and Ball. The intensities are our own estimates from the published photographs by Petrikaln and

PO (*contd.*)

by Ghosh and Ball. All the bands are double-headed, the separation between the P and Q heads being about 1.3 Å.; only the P heads are given below.

λ	I	v', v''	λ	I	v', v''	λ	λ	v', v''
2721.5	1	0, 3 P ₁	2595.7	2	2, 4 P ₂	2387.9	7	2, 1 P ₁
2706.8	3	1, 4 P ₁	2555.0	10	0, 1 P ₁	2383.5	8	1, 0 P ₂
2705.1	1	0, 3 P ₂	2543.9	7	1, 2 P ₁	2379.9	2	3, 2 P ₁
2692.4	4	2, 5 P ₁	2540.4	10	0, 1 P ₂	2375.2	7	2, 1 P ₂
2690.8	4	1, 4 P ₂	2529.4	7	1, 2 P ₂	2367.3	2	3, 2 P ₂
2676.7	4	2, 5 P ₂	2518.7	5	2, 3 P ₂	2320.6	3	2, 0 P ₁
2662.9	3	3, 6 P ₂	2477.9	10	0, 0 P ₁	2313.7	4	3, 1 P ₁
2636.3	7	0, 2 P ₁	2468.3	6	1, 1 P ₁	2306.9	4	4, 2 P ₁
2623.4	7	1, 3 P ₁	2464.2	10	0, 0 P ₂	2301.7	4	3, 1 P ₂
2620.5	8	0, 2 P ₂	2459.0	2	2, 2 P ₁	2300.4	3	5, 3 P ₁
2610.7	2	2, 4 P ₁	2454.6	6	1, 1 P ₂	2294.9	3	4, 2 P ₂
2608.0	7	1, 3 P ₂	2396.3	8	1, 0 P ₁	2288.2	2	5, 3 P ₂

Pb₂

Occurrence. Absorption by lead vapour; also in thermal emission.

Appearance. Degraded to the red. Long $v'' = 0$ progression.

Reference. E. N. Shawhan, *P.R.*, **48**, 343. (1935)†.

Bands in region 5200–4600 Å. Strongest heads: $\lambda\lambda$ 4890.2 (6, 0), 4855.0 (7, 0), 4821.0 (8, 0).

PbBr

VISIBLE SYSTEM

Occurrence. In absorption.

Appearance. Degraded to red.

Reference. F. Morgan, *P.R.*, **49**, 47. (1936).

Strongest bands:—

λ	v', v''	λ	v', v''
5092.1	0, 6	4818.5	2, 2
5040.4	0, 5	4597.1	6, 0
5002.0	1, 5	4566.9	7, 0
4902.5	1, 3	4537.5	8, 0
4866.4	2, 3	4509.5	9, 0

ULTRA-VIOLET SYSTEM

Occurrence. Absorption by heated PbBr₂ at low pressure.

Appearance. Degraded to shorter wave-lengths.

Reference. R. Newburgh and K. Wieland, *Helv. Phys. Acta.*, in press.

Strongest bands:—

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
2964.0	7	0, 4	2906.6	9	1, 2	2868.3	9	2, 1
2946.1	8	0, 3	2893.8	7	0, 0	2851.9	10	2, 0
2928.6	9	0, 2	2889.5	10	1, 1	2831.2	10	3, 0
2911.0	8	0, 1	2872.6	9	1, 0	2811.4	10	4, 0
						2791.7	8	5, 0

PbCl

VISIBLE SYSTEM

Occurrence. High-frequency discharge through PbCl₂ vapour, and in absorption. Also fluorescent emission.

Appearance. Degraded to red.

References. G. D. Rochester, *P.R.S.*, 153, 407. (1935)†.

F. Morgan, *P.R.*, 49, 47. (1936).

Strongest bands (intensities listed by Rochester as 9 or 10) :—

λ	v', v''	λ	v', v''	λ	v', v''
5358.3	4, 14	5062.0	0, 7	*4596.0	1, 1
5342.1	3, 13	4988.2	0, 6	*4548.9	2, 1
5263.1	3, 12	4916.5	0, 5	*4399.0	4, 0
5169.5	2, 10	*4846.0	0, 4	*4356.5	5, 0
5153.4	1, 9	*4660.3	1, 2		

* Observed in absorption but not in emission, probably because of self-absorption.

ULTRA-VIOLET SYSTEM

Occurrence. In absorption through heated PbCl₂ at low pressure.

Appearance. Degraded to violet. Marked sequences.

Reference. R. Newburgh and K. Wieland, *Helv. Phys. Acta.*, in press.

Strongest bands :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
2907.9	7	0, 3	2804.0	9	1, 0	2683.5	8	7, 2
2882.9	9	0, 2	2775.4	9	2, 0	2679.1	8	8, 3
2858.0	10	0, 1	2746.9	8	3, 0	2657.6	8	8, 2
2833.7	7*	0, 0	2721.4	7	8, 5	2652.9	8	9, 3
2827.7	7	1, 1	2688.5	7	6, 1	2648.4	6	10, 4
						2628.0	6	10, 3

* Masked by Pb line 2833.1 A.

PbF

VISIBLE SYSTEM

Occurrence. High-frequency discharge through lead fluoride vapour, and in absorption.

Appearance. Degraded to red. Marked sequences.

References. G. D. Rochester, *P.R.S.*, 153, 407. (1935)†.

F. Morgan, *P.R.*, 49, 47. (1936).

Heads of strong sequences :—

λ	Sequence
4647.7	0, 2
4542.5	0, 1
4441.2	0, 0
4364.8	1, 0

ULTRA-VIOLET SYSTEM, 2882–2584 A.

Occurrence. In absorption at about 800° C. at low pressure.

Appearance. Degraded to shorter wave-lengths.

PbF (*contd.*)

Reference. R. Newburgh and K. Wieland, *Helv. Phys. Acta.*, in press.

Strongest heads :—

λ	I	v', v''	λ	I	v', v''
2841.0	9	0, 1	2746.8	6	2, 1
2800.8	10	0, 0	2709.2	7	2, 0
2754.0	10	1, 0	2702.5	6	3, 1

PbH

References. W. W. Watson, *P.R.*, **54**, 1068. (1938).

W. W. Watson and R. Simon, *P.R.*, **57**, 708. (1940).

5560 A. SYSTEM, ${}^2\Sigma \rightarrow {}^2\Sigma$

Band spectrum of the many-lined type, obtained with 1000 v. lead arc in hydrogen at pressures of four to five atmospheres. Each band possesses four branches degraded to the red. Origins :—

λ	v', v''	λ	v', v''
8446	0, 4	6068.4	1, 1
7595	0, 3	5907.7	2, 1
7329	1, 3	5758.5	3, 1
6870.4	0, 2	5561.0	1, 0
6651.5	1, 2	5425.8	2, 0
6459.0	2, 2	5299.5	3, 0
		5180.7	4, 0

A further faint band at 3815 A. was also reported.

PbIVISIBLE SYSTEM, $\lambda\lambda 6511-4485$

Occurrence. In high frequency discharge, and also weakly in absorption.

Appearance. Degraded to the red. In emission the strongest bands are in the region 6500–5400 A., and in absorption 4800–4500 A.

Reference. R. Newburgh and K. Wieland, *Helv. Phys. Acta.*, in press.

The following are the strongest bands in emission. The values of v' and v'' may be uncertain by one or two units.

λ	v', v''	λ	v', v''	λ	v', v''
6218.1	0, 26	5995.9	0, 22	5747.1	1, 18
6162.8	0, 25	5948.6	1, 22	5699.1	1, 17
6108.0	0, 24	5845.9	1, 20	5651.4	1, 16
6052.4	0, 23	5795.9	1, 19	5557.6	1, 14

ULTRA-VIOLET SYSTEM, $\lambda\lambda 3086-2680$

Occurrence. In absorption through heated PbI_2 at low pressure.

Appearance. Degraded to red.

Reference. R. Newburgh and K. Wieland, *Helv. Phys. Acta.*, in press.

PbI (*contd.*)

Strongest bands :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
2994.2	8	1, 2	2931.8	10	3, 0	2863.4	8	8, 1
2980.1	7	1, 1	2915.0	10	4, 0	2861.0	9	9, 2
2963.1	8	2, 1	2898.7	10	5, 0	2848.0	9	9, 1
2949.0	8	2, 0	2882.5	7	6, 0	2827.4	7	12, 3
						2789.0	7	13, 1

PbO

Five band systems known as A, B, C, D, and E, are attributed to lead oxide.

Occurrence. All five systems have been observed in absorption in a carbon arc furnace. Systems A, B, and D are emitted by an arc (between carbon or copper electrodes) containing lead or lead salts and in flame sources. System C also occurs in emission in a heavy-current discharge.

References. S. Bloomenthal, *P.R.*, **35**, 34. (1930).

A. Christy and S. Bloomenthal, *P.R.*, **35**, 46. (1930).

H. G. Howell, *P.R.S.*, **153**, 683. (1935-6).

L. Withrow and G. M. Rassweiler, *Ind. Eng. Chem.*, **23**, 769. (1931) †

SYSTEM A, $\lambda\lambda 6720-4748$

Appearance. Degraded to red.

Transition. Probably ${}^1\Sigma \rightarrow {}^1\Sigma$, ground state.

Strong bands. Intensities (for emission) on scale of 6.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
6433.6	3	3, 8	5677.8	6	0, 3
6427.7	3	0, 6	5617.6	3	2, 4
6342.0	3	2, 7	5459.4	6	0, 2
6250.7	5	1, 6	5331.1	3	1, 2
6160.5	4	0, 5	5138.2	3	1, 1
5910.7	6	0, 4	5068.8	1	0, 0

SYSTEM B, $\lambda\lambda 5770-4146$

Appearance. Degraded to red. A strong progression on each side of the weak (0, 0) band.

Transition. To ground state.

Strong bands. Intensities (for emission) on scale of 6.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
5353.8	3	0, 5	4553.7	6	1, 1
5162.3	6	0, 4	4509.2	1	0, 0
4983.8	6	0, 3	4410.4	5	1, 0
4816.9	6	0, 2	4317.1	4	2, 0
4658.0	5	0, 1	4229.0	4	3, 0

PbO (*contd.*)**SYSTEM C, $\lambda\lambda 4156-3607$**

Degraded to red. Intensities for absorption. Strong bands :—

λ	I	v', v''
4156.2	3	0, 1
4037.6	3	0, 0
3987.7	4	2, 1
3955.0	7	1, 0
3877.8	8	2, 0
3804.9	6	3, 0

SYSTEM D, $\lambda\lambda 3594-3209$

Appearance. Degraded to red.

Transition. Probably $^1\Sigma \rightarrow ^1\Sigma$, ground state.

Bands as observed by Bloomenthal in emission. Many more bands have been observed in absorption.

λ	I	v', v''	λ	I	v', v''
3594.2	1	1, 4	3341.8	2	1, 1
3485.7	6	0, 2	3320.7	1	0, 0
3442.8	1	2, 3	3264.4	2	1, 0
3401.9	5	0, 1	3209.2	2	2, 0

SYSTEM E, $\lambda\lambda 3062-2780$

Reference. E. E. Vago and R. F. Barrow, *Proc. Phys. Soc.*, **59**, 449. (1947).

This is Howell's system F, but with modified analysis. The following are the strongest bands as recorded by Vago and Barrow :—

λ	I	v', v''	λ	I	v', v''
3062.7	4	0, 3	2925.6	3	2, 2
2998.5	4	0, 2	2900.2	4	1, 1
2960.7	3	1, 2	2866.2	5	2, 1

PbS

Numerous bands, from the near infra-red to the ultra-violet, all degraded to the red, have been obtained in absorption. They have been analysed into six systems, denoted A to F.

References. G. D. Rochester and H. G. Howell, *P.R.S.*, **148**, 157. (1935)†.

E. E. Vago and R. F. Barrow, *Proc. Phys. Soc.*, **59**, 449. (1947)†.

The following are the strongest bands. Systems A to E are from Rochester and Howell and are nearly all listed as intensity 10. System F from Vago and Barrow.

SYSTEM A

λ	v', v''	λ	v', v''	λ	v', v''
5999.1	0, 5	5228.5	3, 1	4919.9	6, 0
5630.2	1, 3	5159.0	4, 1	4858.5	7, 0
5549.1	2, 3	5047.5	4, 0	4798.5	8, 0
5499.8	1, 2	4982.7	5, 0		

PbS (contd.)**SYSTEM B**

λ	v', v''	λ	v', v''
4563.5	2, 1	4316.5	5, 0
4421.3	3, 0	4266.4	6, 0
4368.1	4, 0		

SYSTEM C

λ	I	v', v''
3923.5	8	8, 0
3881.4	9	9, 0
3840.4	8	10, 0

SYSTEM D

λ	I	v', v''
3796.0	8	5, 0
3757.5	8	6, 0
3720.0	8	7, 0

SYSTEM E

λ	v', v''	λ	v', v''
3530.6	0, 3	3428.3	0, 1
3478.7	0, 2	3393.9	1, 1
3443.4	1, 2	3313.2	2, 0

SYSTEM F

The following heads are prominent on Vago and Barrow's plate : 2151.9 (0, 3), 2132.5 (0, 2), 2115.9 (1, 2), 2097.2 (1, 1).

PbSe

Four systems, A, B, C and D, are known, all degraded to the red. The first three have been obtained in absorption by Walker *et al.*, and system D in emission in a discharge tube by Barrow and Vago.

References. J. W. Walker, J. W. Straley and A. W. Smith, *P.R.*, 53, 140. (1938).

R. F. Barrow and E. E. Vago, *Proc. Phys. Soc.*, 56, 76. (1944)†.

Strongest bands only.

SYSTEM A

λ	I	v', v''	λ	I	v', v''
5979.2	8	1, 7	5278.7	10	5, 2
5674.3	9	2, 5	5203.2	10	10, 4
5372.6	10	3, 2	5202.6	10	5, 1
5325.1	10	4, 2	5158.6	10	6, 1

SYSTEM B

4921.2 (1, 3), 4855.9 (1, 2), 4813.1 (2, 2), 4791.3 (1, 1), 4749.0 (2, 1), 4708.4 (3, 1), 4570.9 (5, 0).

PbSe (contd.)**SYSTEM C**

4165.9 (4, 0), 4134.9 (5, 0), 4104.9 (6, 0).

SYSTEM D

λ	I	v', v''	λ	I	v', v''
3713.4	7	6, 1	3557.8	10	1, 0
3676.2	7	5, 1	3534.1	8	1, 1
3628.8	7	3, 0	3500.0	7	0, 1
3593.2	10	2, 0	3477.1	8	0, 2

PbTe

Two systems, both degraded to the red, have been observed in absorption.

Reference. J. W. Walker, J. W. Straley and A. W. Smith, *P.R.*, **53**, 140. (1938).

The following are the strongest heads :—

System A., $\lambda\lambda 5777.3, 5731.7, 5686.8$.

System B., $\lambda\lambda 5054.4, 5018.0, 4965.3, 4930.8, 4896.4, 4863.3$.

PrO

Occurrence. In flame or arc fed with præsodymium salts.

Reference. W. W. Watson, *P.R.*, **53**, 639. (1938).

Heads of strongest sequences (degraded to the red) :—

λ	I
5763.4	9
5691.0	10
5596.6	8
5352.0	

Bands, including the above, have also been observed by G. Piccardi (*Accad. Lincei. Atti.*, **23**, 358 (1936)) and by C. J. Rodden and O. S. Plantinga (*P.R.*, **45**, 280 (1934)).

PtO?

Reference. M. W. Feast, *Ph.D. Thesis*, London (1949), *Proc. Phys. Soc.*, **A63**, 549. (1950).

Bands at 6180, 5906 and 5664 Å. have been observed in a high tension arc in O₂ between platinum electrodes.

Rb₂

Several band systems have been observed and attributed to the rubidium molecule. For most of these wave-lengths and intensities are not available.

References. J. C. McLennan and D. S. Ainslie, *P.R.S.*, **103**, 304. (1923)†.

J. M. Walter and S. Barratt, *P.R.S.*, **119**, 257. (1928).

E. Matuyama, *Nature, Lond.*, **133**, 567. (1934).

λ8800 SYSTEM

Bands observed in absorption by Matuyama.

Rb₂ (*contd.*)**RED SYSTEM**

Observed in absorption and fluorescence. Matuyama gives $\nu_e = 14666 \text{ cm.}^{-1}$. McLennan and Ainslie record the following wave-lengths: 7099.7, 7065.3, 7030.1, 6997.8, 6967.1, 6937.9, 6909.6, 6884.1, 6858.6, 6832.2, 6807.3, 6792.3, 6781.3, 6763.0, 6744.8, 6725.5, and 6706.3. The bands are degraded to longer wave-lengths.

ORANGE SYSTEM

Walter and Barratt report bands at $\lambda\lambda 6054, 6033$ and 5992 , degraded to the red, in absorption.

 $\lambda 4800$ SYSTEM

Observed in absorption. Matuyama gives $\nu_e = 20930 \text{ cm.}^{-1}$. Walter and Barratt record a strong head at $\lambda 4746$ and weaker heads at 5081 and 4703 .

 $\lambda 4350$ SYSTEM

Observed in absorption. Matuyama gives $\nu_e = 22968 \text{ cm.}^{-1}$.

RbCd

Diffuse bands, degraded to the violet, observed in absorption by Barratt (see CsCd). Heads $\lambda\lambda 4487$ and 4423 . Also bands $4400-4200 \text{ \AA}$.

RbCl

The heated vapour shows strong continuous absorption in the middle ultra-violet, merging into diffuse banded absorption in the near ultra-violet.
Reference. K. Sommermeyer, *Z.P.*, **56**, 548. (1929).

RbCs

A diffuse band at $\lambda 5640$ has been observed by J. M. Walter and S. Barratt (*P.R.S.*, **119**, 257. (1928)) in absorption.

RbF

Reference. A. D. Caunt and R. F. Barrow, *Nature, Lond.*, **164**, 753. (1949).
In absorption by heated vapour there is a strong narrow region of continuum around 2150 \AA , with weak bands on the long wave-length side, extending at high temperature to 2980 \AA .

RbH**5300 A. SYSTEM**

Occurrence. In discharge tubes containing a mixture of hydrogen and rubidium vapour. By analogy with the other alkali-metal hydrides it may be expected to

RbH (*contd.*)

occur in the rubidium arc in hydrogen, and in absorption from a mixture of hydrogen and rubidium vapour.

Appearance. A very extensive many-line system with weak R heads degraded to the red.

Transition. $^1\Sigma \rightarrow ^1\Sigma$, ground state.

Reference. A. G. Gaydon and R. W. B. Pearse, *P.R.S.*, **173**, 28. (1939)†.

			Origins of the strongest bands.		
v', v''	λ	I	v', v''	λ	I
1, 2	5871.4	8	6, 1	5193.5	8
2, 2	5783.4	10	4, 0	5098.1	5
3, 2	5696.2	10	5, 0	5028.1	5
4, 2	5610.1	8	6, 0	4959.3	5
2, 1	5502.9	7	7, 0	4892.1	7
3, 1	5423.9	8	8, 0	4826.3	5
4, 1	5345.8	9	9, 0	4762.2	5
5, 1	5268.9	9	10, 0	4699.9	4

RbHg

Diffuse bands, degraded to the violet, observed in absorption by Barratt (see CsCd). Heads $\lambda\lambda 6364, 6335$ and 4879 . Also mention of bands $\lambda\lambda 4400-4200$.

RbI

The heated vapour shows strong continuous absorption in the near ultra-violet, merging into diffuse banded absorption in the violet.

Reference. K. Sommermeyer, *Z.P.*, **56**, 548. (1929).

RbZn

Mention of absorption bands $\lambda\lambda 4400-4200$. See CsCd.

S₂

Occurrence. In sources containing sulphur vapour, especially vacuum-tube discharge, arc, and flame of CS₂ burning in oxygen. The bands occur readily as an impurity in flames containing H₂.

Appearance. Degraded to red. Very extensive system of roughly equally-spaced bands. In flames containing H₂, bands of the $v' = 0$ progression are usually outstanding. See Plate 9.

Transition. $^3\Sigma \rightarrow ^3\Sigma$, ground state.

References. A. Christy and S. M. Naudé, *P.R.*, **37**, 903. (1931).

W. E. Curtis and S. Tolansky, *Durham Phil. Soc.*, p. 323. (1931)†.

A. Fowler and W. M. Vaidya, *P.R.S.*, **132**, 310. (1931)†.

Most of the strong heads of the very extensive main system of bands are listed below. The v', v'' values are from Fowler and Vaidya. Wave-lengths greater than 4800 are from Curtis and Tolansky, and other wave-lengths are those given by

S_2 (contd.)

Fowler and Vaidya reduced by 0.2 A. Intensities for CS_2 flame are on a scale of 1 to 6.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
6165.8	1	9, 30	4651.1	4	3, 17	3321.0	1	3, 4
6102.3	2	8, 29	4609.8	5	2, 16	3290.5	3	2, 3
6039.1	2	7, 28	4563.0	4	1, 15	3259.7	2	1, 2
5980.8	1	6, 27	4523.3	2	0, 14	3244.5	3	3, 3
5962.2	3	9, 29	4478.6	4	2, 15	3215.9	2	2, 2
5900.7	4	8, 28	4433.4	6	1, 14	3203.0	2	4, 3
5840.6	4	7, 27	4394.8	2	0, 13	3171.3	2	3, 2
5783	2	6, 26	4354.8	2	2, 14	3160.9	1	5, 3
5769.5	3	9, 28	4310.8	6	1, 13	3143.5	1	2, 1
5710.1	4	8, 27	4274.2	3	0, 12	3132.2	3	4, 2
5651.6	4	7, 26	4193.6	6	1, 12	3101.3	1	3, 1
5596.4	3	6, 25	*4157.0	5	0, 11	3091.5	5	5, 2
5530.0	3	8, 26	4080.8	3	1, 11	3063.4	3	4, 1
5472.8	4	7, 25	*4045.6	6	0, 10	3054.7	3	6, 2
5418.8	4	6, 24	*3938.9	6	0, 9	3032.9	1	3, 0
5359.0	3	5, 23	3909.4	1	2, 10	3024.6	4	5, 1
5309.2	3	4, 22	*3837.1	6	0, 8	3017.8	2	7, 2
5249.7	5	6, 23	*3739.8	6	0, 7	2996.8	1	4, 0
5194.2	5	5, 22	3677.4	3	1, 7	*2989.5	4	6, 1
5145.4	4	4, 21	*3645.0	5	0, 6	2959.9	2	5, 0
5090.2	5	6, 22	3587.2	5	1, 6	*2954.0	4	7, 1
5036.2	6	5, 21	3555.6	3	0, 5	2926.4	2	6, 0
4989.5	6	4, 20	3500.3	5	1, 5	*2920.2	4	8, 1
4937	5	3, 19	3469.4	2	0, 4	2892.3	4	7, 0
4893.6	5	2, 18	3450.8	2	2, 5	2887.9	4	9, 1
4842.1	6	4, 19	3416.8	4	1, 4	*2860.0	3	8, 0
4790.6	6	3, 18	3386.8	1	0, 3	*2829.1	3	9, 0
4747.4	5	2, 17	3369.4	4	2, 4	2798.8	3	10, 0
4698.8	3	1, 16	3336.5	2	1, 3	2769.4	3	11, 0

* Fainter head to violet.

SH

Reference. M. N. Lewis and J. V. White, *P.R.*, 55, 894. (1939).

3237 A. SYSTEM, $^2\Sigma \rightarrow ^2\Pi_i$

Analogous to the OH bands and degraded to the red. Obtained in absorption by passing repeated flashes from a source of continuum through a discharge tube in which HS radicals were formed by pulses of radio frequency current synchronised to precede the flashes by a very short interval. The band does not appear at all readily in emission, but has been observed by Gaydon in flames of hydrocarbons containing SO_2 or H_2S .

v', v''	R_1	Heads $\lambda(I)$	Q_2
0, 0	3236.6 (8)	3240.7 (7)	3279.1 (4)

SO

Occurrence. In almost all sources containing sulphur and oxygen. The bands are strongly developed in vacuum tubes containing sulphur dioxide, especially with a mildly-condensed discharge. They have also been obtained in absorption by the gases from a discharge through SO₂.

Appearance. Degraded to red. Single-headed bands with rather extended rotational structure. See Plate 10.

Transition. ${}^3\Sigma \rightarrow {}^3\Sigma$, ground state.

References. V. Henri and F. Wolff, *J. Phys. Radium*, **10**, 81. (1929)†.

E. V. Martin, *P.R.*, **41**, 167. (1932)†.

Measurements of strong bands by Martin; weak bands by Henri and Wolff. Intensities by Henri and Wolff.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
3941.6	0	1, 14	3271.0	10	0, 8	2699.1	4	2, 3
3903.6	1	0, 13	3247.5	1	2, 9	2664.8	5	1, 2
3862.7	3	2, 14	3164.8	10	0, 7	2655.6	1	3, 3
3811.8	5	1, 13	3064.1	10	0, 6	2630.1	1	0, 1
3761.6	2	0, 12	3007.9	2	1, 6	2622.2	3	2, 2
3724.7	3	2, 13	2968.5	5	0, 5	2589.0	2	1, 1
3676.2	7	1, 12	2915.4	4	1, 5	2581.1	1	3, 2
3628.2	3	0, 11	2877.7	4	0, 4	2555.5	0	0, 0
3548.7	6	1, 11	2827.4	8	1, 4	2548.6	2	2, 1
3502.1	4	0, 10	2791.3	2	0, 3	2516.4	1	1, 0
3428.1	3	1, 10	2779.8	1	2, 4	2510.4	1	3, 1
3383.1	6	0, 9	2744.0	6	1, 3	2477.7	1	2, 0
3314.8	1	1, 9	2708.6	1	0, 2	2442.0	1	3, 0

SO₂

Sulphur dioxide has a very readily observed absorption band system in the region of 3000 Å. With relatively thick layers of gas the absorption extends from 4000 Å. to 2000 Å., being probably composed of two or more systems. In emission bands have been observed in three regions of the ultra-violet, and in addition there is a weak system of bands observed in the afterglow in the violet.

ABSORPTION SPECTRUM, MAIN SYSTEM

The strong part of this system extends from 3200 to 2600 Å. By using a metre or so of gas at atmospheric pressure, absorption bands can be observed as far as 4000 Å.

Appearance. Degraded to the red. Fairly closely-spaced bands in the region 3200–2750. Below 2750 Å. the bands become diffuse, and the longer wave-length end of the system also consists of narrow headless bands. See Plate 10.

Analysis. The bands are definitely due to the molecule SO₂ and many observers have published what they state to be an analysis of the system, but the agreement between the various authors is poor and it appears that very little reliance can be placed in any existing analysis. That of Clements, who studied the bands at various temperatures, is perhaps the most likely solution.

References. J. H. Clements, *P.R.*, **47**, 224. (1935).

W. C. Price and D. M. Simpson, *P.R.S.*, **165**, 272. (1938)†.

The following are the wave-lengths of the maxima of the strongest bands; these

SO₂ (*contd.*)

maxima are close to the heads, being usually less than 1 A. to the red of the head ; intensities are based on Clements quantitative measurements.

λ	I	λ	I	λ	I	λ	I
3190.9	1	3065.9	5	2906.5	8	2780.0	6
3181.1	1	3043.3	7	2900.9	5	2772.0	4
3173.0	1	3022.1	9	2887.7	9	2765.2	4
3167.0	1	3001.0	10	2868.9	8	2754.6	4
3159.0	2	2980.0	9	2852.0	9	2751.2	4
3151.8	2	2961.2	10	2832.3	8	2738.1	4
3131.3	3	2943.8	9	2818.1	7	2734.6	5
3129.5	?	2937.7	8	2815.5	7	2727.5	3
3108.4	3	2924.8	8	2797.0	8	2685.0	4
3087.7	4	2923.1	8	2789.4	7	2646.6	3

This system has also been observed in fluorescence by Lotmar (*Z.P.*, **83**, 765. (1933)) and is frequently observed in emission spectra of sulphur dioxide superposed, by self-absorption, on the continuous spectrum readily emitted by this molecule.

ABSORPTION SPECTRUM, OTHER BANDS

The following are the strongest absorption bands in the far ultra-violet ; the bands are degraded to the red ; measurements by B. N. Bhaduri. See also Price and Simpson.

$\lambda\lambda$ 2348.0, 2326.5, 2323.9, 2303.5, 2295.5, 2276.2, 2257.5, 2241.5, 2238.6, 2222.9, 2204.5, 2186.6, and 2168.3.

J. Duchesne and B. Rosen (*J. Chem. Phys.*, **15**, 631 (1947)) have given an analysis of this system which they refer to as the α system.

EMISSION SPECTRUM

Occurrence. In mild uncondensed discharges through flowing SO₂.

References. W. H. Bair, *Astrophys. J.*, **52**, 301. (1920).

T. Chow, *P.R.*, **44**, 638. (1933).

B. N. Bhaduri, *Ph. D. Thesis*, London.

The emission spectrum is best considered in three regions ; the measurements are by Bhaduri.

A. Region 4340–2700 A.

Very complex mass of bands degraded to the red, strongest heads : $\lambda\lambda$ 3691.8, 3668.7, 3557.7, 3359.2, 3343.4, 3228.7, 3158.1, 3122.0.

B. Region 2640–2350 A.

A strong group of bands between 2640 and 2490 A., and weaker bands extending to 2350 A. ; degraded to longer wave-lengths. Strongest heads : $\lambda\lambda$ 2622.2, 2606.6, 2595.8, 2585.5, 2579.7, 2568.0, 2558.6, 2552.6, 2541.8, 2532.6, 2526.5, 2516.2, 2507.3, 2493.0, 2482.8, 2458.8, 2411.4, 2396.1. See Plate 10.

C. Region 2343–2170 A.

A relatively simple group of close double-headed bands degraded to the red.

SO₂ (*contd.*)

Strong bands :—

λ	I	λ	I
2342.6	5	2281.1	2
2321.9	6	2261.8	4
2302.0	5	2243.6	4

AFTERGLOW SPECTRUM

Occurrence. In afterglow of discharge through SO₂.*Appearance.* Narrow headless bands often occurring in pairs.*Reference.* A. G. Gaydon, *P.R.S.*, **146**, 901. (1934)†.Maxima of strongest bands : λ 44461.0, 4361.1, 4265.3, 4244.6, 4152.9, 4066.5, 4048.3, 3963.7, 3883.0.**Sb₂**

Two systems in the ultra-violet have been observed in absorption. All the bands are degraded to the red.

References. S. M. Naudé, *P.R.*, **45**, 280. (1934).J. Genard, *P.R.*, **44**, 468. (1933).G. Nakamura and T. Shidei, *Japan. J. Phys.*, **10**, 11. (1935).

The following measurements are by Nakamura and Shidei :—

SYSTEM II, λ 2333–2178

Strongest bands :—

λ	I	v', v''
2272.2	4	0, 3
2258.5	4	0, 2
2244.9	5	0, 1
2222.8	7	2, 1
2209.4	5	2, 0

SYSTEM III, λ 2168–2048Strongest bands : λ 2138.6, 2126.8, 2115.0, 2104.3.Nakamura and Shidei's System I, consisting of bands around 2900 A., appears to be due to SO₂.**SbBi**A system of bands λ 2528–2399 have been observed in absorption by a mixture of antimony and bismuth vapours. They are degraded to the red.*Reference.* G. Nakamura and T. Shidei, *Japan. J. Phys.*, **10**, 11. (1935)†.

The following are the strongest bands :—

λ	I	v', v''
2514.0	2	0, 4
2500.6	4	0, 3
2487.4	4	0, 2
2473.7	4	0, 1
2462.2	2	1, 1
2460.4	3	0, 0
2449.0	2	1, 0

SbCl

Occurrence. SbCl₃ in active nitrogen.

Appearance. Degraded to the red. Two sub-systems of bands between 4200 and 5600 Å. The strongest bands form two long $v' = 0$ progressions.

Reference. W. F. C. Ferguson and I. Hudes, *P.R.*, 57, 705. (1940)†.

The following are the strongest heads :—

λ	<i>I</i>	v', v''	First Sub-system			Second Sub-system		
			λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
5333.8	5	0, 10	4902.0	4	1, 6	4575.0	4	0, 11
5236.0	4	0, 9	4872.9	3	0, 5	4503.6	4	0, 10
5141.0	4	0, 8	4816.1	3	1, 5	4434.0	4	0, 9
5048.6	4	0, 7	4680.8	3	2, 4	4365.0	4	0, 8
4959.7	4	0, 6				4298.4	4	0, 7
						4233.0	3	0, 6

SbF

Occurrence. Antimony fluoride in active nitrogen.

Reference. G. D. Rochester, *P.R.*, 51, 486. (1937)†.

SYSTEM A, $\lambda\lambda 5200-3600$

Degraded to the red. Strongest bands : $\lambda\lambda 4406.6$ (0, 2), 4292.6 (0, 1), 4183.6 (0, 0), 4111.9 (1, 0), and 4043.2 (2, 0).

SYSTEM B, $\lambda\lambda 2700-2500$

Degraded to shorter wave-lengths. Strongest heads : $\lambda\lambda 2714$, 2630 and 2572.

SYSTEMS C₁ and C₂, $\lambda\lambda 2430-2200$

Degraded to shorter wave-lengths. No measurements available.

SbN

Occurrence. Discharge through mixture of antimony vapour and N₂.

Appearance. Degraded to red. Close double-headed bands forming fairly well-marked sequences.

Reference. N. H. Coy and H. Spomer, *P.R.*, 58, 709. (1940).†

The following are the R heads. Intensities are our estimates from published photograph and description. Strong bands only.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3166.1	5	1, 4	2995.3	7	1, 2
3062.3	5	8, 9	2985.7	9	0, 1
3052.8	5	7, 8	2924.1	4	2, 2
3015.5	5	3, 4	2912.0	7	1, 1
3004.5	7	2, 3	2904.3	10	0, 0

SbO

Occurrence. Metallic antimony in carbon arc in air.

Appearance. Bands throughout the visible and near ultra-violet, degraded to the red. Some of the bands may show close double heads.

References. B. C. Mukherji, *Z.P.*, 70, 552. (1931)†.

A. K. Sen Gupta, *Indian J. Phys.*, 13, 145 (1939); 17, 216 (1943).

SbO (contd.)

There is some doubt about the vibrational analysis. Mukherji arranged the bands into four systems, A, B, C and D, while Sen Gupta measured a larger number of bands and made them into two double systems, and later found a new system further to the ultra-violet. All systems are believed to have the same 2I final state. In the absence of intensity estimates or good published spectrograms it is difficult to comment on Sen Gupta's analysis. It is provisionally used here, and bands which appear strongly on Mukherji's plates, or which are likely to be strong (in the red region), are listed below.

LESS REFRACTIBLE SYSTEM

First Sub-system		Second Sub-system			
λ	v', v''	λ	v', v''	λ	v', v''
6559.1	0, 4	5750.7	0, 4	5065.0	0, 1
6240.2	0, 3	5505.6	0, 3	4926.2	1, 1
5949.4	0, 2	5341.2	1, 3	4795.8	2, 1
5757.9	1, 2	5277.7	0, 2	4675.0	3, 1
		5189.9	2, 3	4617.2	2, 0
		5126.3	1, 2	4504.7	3, 0

MORE REFRACTIBLE SYSTEM

First Sub-system		Second Sub-system			
λ	v', v''	λ	v', v''	λ	v', v''
4272.7	0, 1	3894.8	0, 1	3583.1	—
4130.2	0, 0	3774.0	0, 0	3568.1	—
4075.0	2, 1	3695.0	1, 0	3469.2	—
3987.9	3, 1	3672.2	9, 5	3460.6	6, 1
		3656.8	3, 1	3402.4	7, 1
		3621.7	2, 0	3373.6	11, 3

SEN GUPTA'S ULTRA-VIOLET SYSTEM

These are the P heads of what are probably the strongest bands.

First Sub-system		Second Sub-system	
λ	v', v''	λ	v', v''
2724.0	0, 1	2565.2	0, 1
2665.9	0, 0	2513.2	0, 0
2661.0	1, 1	2509.5	1, 1
2605.4	1, 0	2459.6	1, 0

ScO

A strong band system in the orange and a weaker system in the blue-green have been attributed to scandium oxide.

Occurrence. Scandium salts in an arc.

Reference. W. F. Meggers and J. A. Wheeler, *Bur. Stand. J. Res.*, **6**, 239. (1931)†.

ScO (contd.)

ORANGE SYSTEM, $\lambda\lambda 7300-5740$

Appearance. Degraded to longer wave-lengths. Rather widely-spaced double double-headed bands. Long sequences.

Transition. A ${}^2\Pi \rightarrow X {}^2\Sigma$, ground state.

The following are the strong heads at the beginning of the three principal sequences. Intensities are based on Meggers and Wheeler's, but reduced to a scale of 10.

λ	I	v', v''	λ	I	v', v''
5736.8	1	1, 0 i Q	6017.1	6	0, 0 i R
5764.4	1	1, 0 ii R	6036.2	10	0, 0 i Q
5772.7	2	2, 1 i Q	6064.3	7	0, 0 ii R
5809.8	3	3, 2 i Q	6072.6	8	1, 1 i Q
5811.6	2	2, 1 ii Q	6079.3	8	0, 0 ii Q
5847.7	3	4, 3 i Q	6101.9	5	1, 1 ii R
5849.1	3	3, 2 ii Q	6109.9	6	2, 2 i Q
5887.4	3	4, 3 ii Q	6116.0	6	1, 1 ii Q
5928.1	2	5, 4 ii Q			
5959.0	1	6, 5 ii R	6437.1	1	0, 1 ii R
5968.5	1	6, 5 ii Q	6446.2	5	1, 2 i Q
			6495.9	2	1, 2 ii Q
			6525.6	2	3, 4 i Q

BLUE-GREEN SYSTEM, $\lambda\lambda 5330-4500$

Appearance. Close double-headed bands (separation 0.3 A.) degraded to the red.

Transition. B ${}^2\Sigma \rightarrow X {}^2\Sigma$, ground state.

The following are the first (R) heads of the strong bands :—

λ	I	v', v''
5096.7	4	0, 1
4857.8	5	0, 0
4707.0	2	2, 1
4672.6	2	1, 0
4571.8	2	4, 2
4536.6	1	3, 1
4502.8	1	2, 0

Se₂

A very extensive group of bands has been attributed to selenium Se₂. These bands have been analysed into several systems, but Asundi and Parti have recently expressed the opinion that all the absorption and emission bands observed in discharge tubes belong to one extensive system which, however, shows marked irregularities due presumably to perturbations.

There is also a weak system between 6800 and 6000 A. which has been observed in a high-frequency electrodeless discharge by Rosen and Monfort.

Absorption bands in the ultra-violet observed by Moraczewska are attributed to selenium oxide by Asundi and Parti.

References. B. Rosen, *Z.P.*, **43**, 69. (1927).

T. E. Nevin, *Phil. Mag.*, **20**, 347. (1935).

B. Rosen and F. Monfort, *Bull. Acad. Roy., Belgium*, **22**, 215. (1936).

Se₂ (*contd.*)

R. K. Asundi and Y. P. Parti, *Indian Acad. Sci. Proc.*, **6A**, 207. (1937)†.

B. Rosen, *Physica*, **6**, 205. (1939).

M. Miyanisi, *Inst. Phys. Chem. Res. Tokyo, Res. Pap.*, 955. (1940).

MAIN SYSTEM, α

Occurrence. In absorption and in discharge tubes; the bands have also been observed in fluorescence by Rosen, and flames by Miyanisi.

Appearance. Degraded to longer wave-lengths. In absorption the strong part of the system consists of regularly-spaced bands, but in emission the bands occur in waves, and the structure is very complex.

The following are the strongest bands observed by Nevin in absorption :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3545.4	7	14, 3	3432.0	9	13, 0	3337.1	9	17, 0
3530.4	7	11, 1	3407.1	9	14, 0	3315.3	9	18, 0
3483.5	9	11, 0	3383.2	9	15, 0	3293.9	9	19, 0
3457.3	9	12, 0	3359.7	9	16, 0	3274.0	8	20, 0

There is some doubt about the analysis of the emission bands, and some may be due to SeO₂.

The following are the strong bands (Int. 4 or more) observed by Asundi and Parti in a discharge tube; strongest bands (Int. 6 or more) indicated by asterisk *. $\lambda\lambda$ 5779.6, 5730.8, 5719.3, 5638.0, 5622.3, 5606.8, 5591.3, 5576.0, 5518.5, 5502.4, 5471.4, 5400.9, 5388.3, 5144.2, 5141.0, 5134.3, 4819.6, 4591.8, 4596.3, 4303.0*, 4258.0, 4255.1*, 4216.9, 4168.6, 4148.9, 4103.9, 4041.7, 4002.9, 3980.7*, 3943.5*, 3907.2*, 3885.9, 3849.9.

The following are the strong bands obtained in a flame by Miyanisi; they form two progressions, and Miyanisi believes these are the $v' = 2$ and 3 progressions :— $\lambda\lambda$ 4217.3, 4177.0, 4153.4, 4112.4, 4089.2, 4049.0, 4026.9, 3988.8, 3965.7, 3929.1, 3906.6, 3871.4, 3849.8, 3815.3, 3793.4, 3760.1, 3706.4.

SeBr₂

Diffuse bands have been observed in absorption. Maxima at $\lambda\lambda$ 5402, 5334, 5267, 5205, 5138*, 5075, 5017 and 4963.

* Strongest band.

Reference. M. Wehrli, *Helvetica Phys. Acta*, **9**, 329. (1936).

SeCl₂

Diffuse bands have been observed in absorption. Maxima at $\lambda\lambda$ 5974, 5854, 5742, 5634, 5531, 5439, 5346, 5257, 5179, 5084, 5031, 4960, 4885, 4806, 4735, and 4659.

Reference. M. Wehrli, *Helvetica Phys. Acta*, **9**, 637. (1936).

SeO

Occurrence. In flames and in discharge tubes.

Appearance. Degraded to red. The bands appear double-headed, the second (longer wave-length) head usually being the stronger.

Reference. Choong Shin Piaw, *Ann. Phys. Paris*, **10**, 173. (1938)†.

The following are the strong bands. Choong Shin Piaw has treated the two

SeO (*contd.*)

heads separately as though to sub-systems A and B; they may be the R and Q heads of the same bands.

λ	I	v', v''	λ	I	v', v''
3942.9	10	0, 9 A	3380.5	6	0, 4 A
3930.7	8	B	3372.1	5	B
3815.6?	10	0, 8 A	3322.1	5	1, 4 A
3807.3	8	B	3314.7	5	B
3700.3	9	0, 7 A	3229.0	6	1, 3 A
3690.2	7	B	3222.0	5	B
3588.3	9	0, 6 A	3139.8	5	1, 2 A
3578.9	7	B	3133.1	2	B
3481.8	9	0, 5 A	3088.8	4	2, 2 A
3473.1	6	B	3084.2	3	B

SeO₂**ULTRA-VIOLET SYSTEM, $\lambda\lambda 3300-2300$**

Occurrence. In absorption. Some of the bands also occur in emission in a discharge tube.

Appearance. Complex system of red-degraded bands, somewhat similar to the corresponding system of SO₂.

References. R. K. Asundi, M. Jan-Khan and R. Samuel, *P.R.S.*, **157**, 28. (1936)†.
Choong Shin Piaw, *Ann. Phys. Paris*, **10**, 173. (1938)†.

The photographs given in the two references are similar, but the recorded wave-lengths differ by up to 4 Å., the intensity estimates show little correlation, and the analyses are quite different. The following are averaged wave-lengths of the heads which appear prominent in the photographs:—

$\lambda\lambda 2985, 2950, 2928, 2893, 2872, 2851, 2818, 2799, 2767, 2748, 2730, 2719, 2699, 2681, 2669, 2653, 2636, 2609, 2600, 2592.$

Duchesne and Rosen (*Physica*, **8**, 540 (1941)) have re-examined this system; their wave-lengths agree better with those of Choong Shin Piaw, but their analysis differs from both the earlier ones.

VISIBLE SYSTEM, $\lambda\lambda 4774-4005$

Reference. J. Duchesne and B. Rosen, *J. Chem. Phys.*, **15**, 631. (1947).

About 70 weak absorption bands are listed, but no intensities are recorded. The bands are degraded to the red and form very long progressions; bands in the centre of the region are diffuse.

Si₂ ?

Occurrence. In H₂ flame charged with SiCl₄.

Reference. A. R. Downie and R. F. Barrow, *Nature, Lond.*, **160**, 198. (1947).

Bands 4200–5700 degraded to violet are provisionally suggested as being due to Si₂. Strongest head 5240 Å.

SiBr

Occurrence. Discharge through streaming SiBr₄ vapour.

Appearance. Degraded to shorter wave-lengths. Bands in region 3233–2875 Å.

Transition. Probably ${}^2\Sigma \rightarrow {}^2\Pi$, ground state.

Reference. W. Jevons and L. A. Bashford, *Proc. Phys. Soc.*, **49**, 554. (1937).

The strongest bands only are listed below ; (i) and (ii) refer to the two components of the system :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3086.8	7	0, 2 (i)	3008.8	10	0, 0 (i)
3047.7	9	0, 2 (ii)	2958.7	7	1, 1 (ii)
3047.3	9	0, 1 (i)	2958.2	7	1, 0 (i)
3009.2	8	0, 1 (ii)	2922.0	7	1, 0 (ii)

SiCl

Occurrence. Discharge through streaming SiCl₄ vapour.

Appearance. Degraded to shorter wave-lengths. Three systems in regions 2942, 2436 and 2232 Å.

Transitions. Three excited states B, C, and D to ground state X, which is probably ${}^2\Pi$.

Reference. W. Jevons, *Proc. Phys. Soc.*, **48**, 563. (1936).

 λ 2942 SYSTEM

The following wave-lengths are for the P heads, i and ii indicating each sub-band. The Q heads lie about 0.6 Å. to the violet.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3117.8	1	1, 5 i	3020.5	6	1, 3 i	2942.2	8	0, 0 i
3097.5	0	1, 5 ii	3017.6	6	0, 2 ii	2924.4	8	0, 0 ii
3085.6	2	0, 3 i	3001.7	4	1, 3 ii	2882.9	8	1, 0 i
3068.7	2	1, 4 i	2988.8	8	0, 1 i	2865.8	8	1, 0 ii
3065.8	3	0, 3 ii	2973.5	4	1, 2 i	2826.1	7	2, 0 i*
3049.3	2	1, 4 ii	2970.4	8	0, 1 ii	2809.7	10	2, 0 ii*
3036.6	4	0, 2 i	2955.0	3	1, 2 ii	2772.0	7	3, 0 i*

* These bands may not belong to this system

 λ 2436 SYSTEM. P heads, i and ii indicating each sub-band.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
2601.5	1	0, 5 i	2521.0	1	0, 3 ii	2424.4	3	0, 0 ii
2588.3	1	0, 5 ii	2500.3	4	0, 2 i	2416.2	2	1, 1 ii
2567.3	1	0, 4 i	2488.2	6	0, 2 ii	2396.7	6	1, 0 i
2557.5	1	1, 5 i	2467.8	6	0, 1 i	2385.6	5	1, 0 ii
2555.5	2	0, 4 ii	2456.0	7	0, 1 ii	2359.1	1	2, 0 i
2544.3	1	1, 5 ii	2435.9		0, 0 i	2348.6	0	2, 0 ii
2533.4	4	0, 3 i	2437.7	2	1, 1 i			

SiCl (*contd.*)

$\lambda 2232$ SYSTEM. P heads, i and ii indicating each sub-band.

λ	I	v', v''	λ	I	v', v''
2341.1	0	0, 4 i	2258.4	5	0, 1 i
2313.1	1	0, 3 i	2247.7	5	0, 1 ii
2285.5	2	0, 2 i	2231.5	4	0, 0 i
2274.7	2	0, 2 ii	2221.2	4	0, 0 ii

SiF

The spectrum of SiF extends from the red to the far ultra-violet and the bands are very numerous. Johnson and Jenkins divided the bands into several systems denoted by the Greek letters α , β , γ , δ , ϵ , ζ , and η . Some of these systems have since been related by Asundi and Samuel.

Occurrence. In discharge through SiF₄.

Appearance. Very complicated systems. Good photographs are reproduced by Johnson and Jenkins. See also Plate 8.

Transitions. α system, ${}^2\Pi \rightarrow {}^2\Pi$, ground state.

β system, B ${}^2\Sigma \rightarrow {}^2\Pi$, ground state.

γ system, C ${}^2\Sigma \rightarrow {}^2\Pi$, ground state.

References. R. C. Johnson and H. G. Jenkins, *P.R.S.*, 116, 327. (1927)†.

R. K. Asundi and R. Samuel, *Proc. Indian Acad. Sci.*, 3, 346. (1936).

E. H. Eyster, *P.R.*, 51, 1078. (1937).

Only a few of the strongest heads are listed below. R, V, and M denote band degraded to longer or shorter wave-lengths or maximum of headless band respectively. Intensities reduced to scale of 10. The β and γ bands have close double heads. The α bands show two strong and two weak heads.

λ	I	v', v''	System.	λ	I	v', v''	System
6594	V	3	ζ	4240.8	R	7	1, 0 R ₁ α
6492	V	5	ζ	4229.7	V	3	ϵ
6416	V	5	ζ	4183.3	V	4	ϵ
6397	V	5	ζ	4011.8	V	4	ϵ
6270	V	2	ζ	3363	M	10	η
4850.5	R	4	3, 5 ${}^Q R_{12}$ α	3346	M	10	η
4569.5	R	5	0, 1 ${}^Q R_{12}$ α	3042.4	V	3	0, 2 P i β
4535.9	R	5	0, 1 R ₁ α	3027.5	V	3	0, 2 P ii β
4531.6	R	6	4, 4 ${}^Q R_{12}$ α	2967.1	V	6	0, 1 P i β
4495.8	R	6	3, 3 ${}^Q R_{12}$ α	2952.8	V	6	0, 1 P ii β
4462.0	R	5	2, 2 ${}^Q R_{12}$ α	2894.4	V	6	0, 0 P i β
4430.2	R	7	1, 1 ${}^Q R_{12}$ α	2880.8	V	6	0, 0 P ii β
4429.8	R	6	2, 2 R ₁ α	2813.0	V	4	1, 0 P i β
4400.5	R	7	0, 0 ${}^Q R_{12}$ α	2800.0	V	4	1, 0 P ii β
4398.3	R	6	1, 1 R ₁ α	2652.8	V	3	0, 2 Q i γ
4388.6	R	2	0, 0 R ₂ α	2641.4	V	3	0, 2 Q ii γ
4368.2	R	10	0, 0 R ₁ α	2595.1	V	5	0, 1 Q i γ
4354.5	R	1	0, 0 ${}^S R_{21}$ α	2584.3	V	5	0, 1 Q ii γ
4334.4	R	5	3, 2 ${}^Q R_{12}$ α	2539.2	V	7	0, 0 Q i γ
4301.3	R	5	2, 1 ${}^Q R_{12}$ α	2528.9	V	7	0, 0 Q ii γ
4270.2	R	5	1, 0 ${}^Q R_{12}$ α				

SiH

References. G. D. Rochester, *Z.P.*, **101**, 769. (1936)†.
C. V. Jackson, *P.R.S.*, **126**, 373. (1930)†.

4142 A. SYSTEM, ${}^2A \rightarrow {}^2\Pi$, GROUND STATE

Complex bands degraded to the red. Obtained in silicon arc in hydrogen, in hydrogen discharge tubes (silicon from glass walls) and in sun-spots.

v', v''	Origins	Heads
0, 0	4126.6	4128 Q ₁
0, 0	4147.8	4142.2 Q ₂
1, 1	—	4184 Q ₁
1, 1	—	4198.6 Q ₂

SiN

There are two band systems attributed to this molecule, a strong system $\lambda\lambda 5260-3786$ and a weak system $\lambda\lambda 5620-3188$.

STRONG SYSTEM

Occurrence. Silicon tetrachloride vapour in active nitrogen.

Appearance. Degraded to red. Single-headed.

Transition. ${}^2\Sigma \rightarrow {}^2\Sigma$, ground state.

References. W. Jevons, *P.R.S.*, **89**, 187. (1913).

F. A. Jenkins and H. de Laszlo, *P.R.S.*, **122**, 105. (1929).

The following table is compiled from the above references. Wave-lengths of R heads. Intensities as given by Jevons.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
4947	1	5, 8	4345.4	2	1, 2	4050.7	8	4, 3
4797	2	7, 9	4317.6	5	6, 6	4032.0	4	8, 6
4748.7	3	6, 8	4277.0	5	5, 5	4016.8	6	3, 2
4705.1	4	5, 7	4260.4	2	9, 8	3989.9	4	7, 5
4664.3	5	4, 6	4239.1	9	4, 4	3985.8	5	2, 1
4629.2	3	3, 5	4211.9	4	8, 7	3957.7	2	1, 0
4618.1	2	8, 9	4204.1	10	3, 3	3949.8	4	6, 4
4569.8	4	7, 8	4172.1	6	2, 2	3911.8	4	5, 3
4524.3	5	6, 7	4168.2	4	7, 6	3814.0	2	2, 0
4482.4	6	5, 6	4143.1	3	1, 1			
4443.1	8	4, 5	4126.6	8	6, 5			
4406.9	8	3, 4	4116.8	1*	0, 0			
4360.7	3	7, 7	4087.4	8	5, 4			

* This intensity is probably too low.

WEAK SYSTEM

Occurrence. Silicon tetrachloride vapour in active nitrogen.

Appearance. Degraded to red. Double-headed, separation 27 cm.⁻¹

Transition. Perhaps ${}^2\Pi \rightarrow {}^2\Pi$.

Reference. R. S. Mulliken, *P.R.*, **26**, 319. (1925).

In the following table the strongest bands listed by Mulliken are given. Intensities have been increased to a scale of 5. Only the shorter wave-length head is listed here.

SiN (contd.)

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
5555.2	2	4, 12	4877.6	2	1, 7	3744.1	2	3, 2
5492.1	2	3, 11	4834.7	2	4, 9	3698.4	1	2, 1
5235.0	3	3, 10	4463.6	2	1, 5	3607.8	2	3, 1
5172.6	5	2, 9	3994.7	4	2, 3	3535.0	4	4, 1
4937.4	2	2, 8	3841.6	1	2, 2	3400.4	1	4, 0

SiO

Occurrence. In flames into which SiCl_4 is introduced, in discharge through SiCl_4 vapour mixed with oxygen, and strongly in arc. Also in absorption.

Appearance. Degraded to red. Single-headed. See Plate 1.

Transition. ${}^1\Pi \rightarrow {}^1\Sigma$, ground state.

References. W. Jevons, *P.R.S.*, **106**, 174. (1924).

D. Sharma, *Proc. Nat. Acad. Sci. India*, **A14**, 37. (1944)†.

The following measurements are by Jevons. Intensities I_a , I_d and I_f are for absorption, discharge tube and flame respectively, the latter being from de Gramont and de Watteville.

λ	I_a	I_d	I_f	v', v''	λ	I_a	I_d	I_f	v', v''
2925.3		2		4, 10	2486.8	7	6	10	0, 2
2898.4		3		3, 9	2481.9	3	2	3	3, 4
2871.6		4		2, 8	2459.0	1	3	4	2, 3
2845.7		2		1, 7	2436.3	1	3		1, 2
2832.2		1		4, 9	2413.8	9	7	8	0, 1
2820.0				0, 6	2410.2				3, 3
2806.3		8		3, 8	2387.9	6	5	3	2, 2
2780.5		7	6	2, 7	2365.7	7	6	1	1, 1
2755.0		6	6	1, 6	2364.5			4	4, 3
2730.1		2		0, 5	2344.3	8	5	4	0, 0
2718.8		4		3, 7	2342.4	1	1	4	3, 2
2693.7		9	7	2, 6	2298.9	10	6	2	1, 0
2669.0		9	8	1, 5	2277.2	4	1	1	3, 1
2644.8		4	4	0, 4	2255.9	7	4		2, 0
2636.0				3, 6	2236.3	4	2	1	4, 1
2611.3		4		2, 5	2215.4	6	2	0	3, 0
2587.1	2	5	8	1, 4	2197.4	4	0		5, 1
2563.8	3	5	8	0, 3	2176.6	5	1		4, 0
2509.9	2	4	3	1, 3	2160.3	5			6, 1

SiO⁺

Occurrence. Heavy current discharge through a silica vacuum tube.

Appearance. A close double-headed band, degraded to the red.

Transition. ${}^2\Sigma \rightarrow {}^2\Sigma$.

References. R. C. Pankhurst, *Proc. Phys. Soc.*, **52**, 707. (1940).

L. H. Woods, *P.R.S.*, **63**, 426. (1943)†.

λ	v', v''
3832.9	0, 0

SiO₂ ?

Occurrence. These bands have been recorded by Cameron as occurring in a silicon arc in oxygen at reduced pressure. They have also been observed by Pankhurst using a heavy-current discharge through a silica vacuum tube.

Appearance. A strong group of bands between 4215 Å. and 4300 Å., consisting of bands degraded in both directions and rather diffuse maxima of intensity; weaker bands, mostly degraded to the red, throughout the violet region.

References. W. H. B. Cameron, *Phil. Mag.*, **3**, 110. (1927)†.
R. C. Pankhurst, *Proc. Phys. Soc.*, **52**, 707. (1940)†.
L. H. Woods, *P.R.*, **63**, 426. (1943).

These bands are of complex structure and it is unlikely that they are emitted by a diatomic molecule. The conditions of their occurrence suggest SiO₂ as the emitter.

The following measurements are by Pankhurst. The letters R, V, or M indicate that the band is degraded to longer or shorter wave-lengths, or that the measurement is of the maximum of intensity of a headless structure, respectively.

λ	<i>I</i>	λ	<i>I</i>	λ	<i>I</i>
4468.5 R	4	4262.8 R	6	4022 M	3
4466.6 R	3	4256.6 R	8	3972 M	4
4417.3 R ?	3	4254.4 R	7	3922 M	4
4408 R ?	4	4252.4 V	6	3791.4 R	2
4392.7 R	2	4240 M	10	3776.9 R	3
4283 M	9	4235.5 V	10	3713.5 R	2
4274.5 R	4	4228.5 V	9		
4269.6 R	4	4071.7 R	1		

SiS

Occurrence. High current-density discharge through quartz tube containing silicon sulphide. A few bands of the strong system have also been obtained in absorption.

Transition. ¹I₁ → ¹Σ, ground state.

References. R. F. Barrow and W. Jevons, *P.R.S.*, **169**, 45. (1938)†.
R. F. Barrow, *Nature, Lond.*, **154**, 364. (1944).

STRONG SYSTEM, λλ3959–2585

Appearance. Degraded to the red. Apparently single-headed bands. The following are the strong bands :—

λ	<i>I</i>	<i>v', v''</i>	λ	<i>I</i>	<i>v', v''</i>	λ	<i>I</i>	<i>v', v''</i>
3506.3	4	3, 11	3244.2	5	2, 7	2883.2	8	1, 1
3471.8	4	5, 12	3221.8	8	1, 6	2863.7	8	0, 0
3447.4	4	4, 11	3149.0	7	1, 5	2822.7	9	1, 0
3423.6	5	3, 10	3127.7	8	0, 4	2783.2	9	2, 0
3399.7	5	2, 9	3078.8	7	1, 4	2764.7	6	4, 1
3343.4	5	3, 9	3057.9	9	0, 3	2745.3	8	3, 0
3320.1	6	2, 8	2990.8	10	0, 2	2708.8	7	4, 0
3297.6	7	1, 7	2926.1	10	0, 1	2673.8	6	5, 0

SiS (*contd.*)**WEAK SYSTEM, $\lambda\lambda 6169-3491$**

Appearance. Degraded to the red. An extensive system of relatively weak bands, which are spaced at regular intervals.

An additional weak system around 2340 A. has been reported in absorption by Vago and Barrow (*Nature, Lond.*, **157**, 77 (1946)).

SiSe

Occurrence. Heavy-current discharge through quartz tube containing aluminium selenide. Also in absorption.

Appearance. Degraded to the red. Single-headed bands.

Reference. R. F. Barrow, *Proc. Phys. Soc.*, **51**, 267. (1939)†.

Strong bands :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3406.0	7	1, 6	3145.3	9	0, 1
3342.2	9	1, 5	3106.4	9	1, 1
3323.7	8	0, 4	3051.8	8	1, 0
3262.4	10	0, 3	3015.8	7	2, 0
3203.0	10	0, 2	2981.1	6	3, 0

A weak system around 2600 A. has been reported in absorption by Vago and Barrow (*Nature, Lond.*, **157**, 77 (1946)).

SiTe

Occurrence. Heavy current through quartz tube containing aluminium and tellurium. Also in absorption.

Appearance. Degraded to the red. Single-headed bands.

Reference. R. F. Barrow, *Proc. Phys. Soc.*, **51**, 45. (1939)†.

Strong bands :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3763.9	8	1, 5	3556.1	10	0, 1
3745.2	9	0, 4	3514.3	10	1, 1
3680.3	9	0, 3	3456.2	8	1, 0
3617.3	10	0, 2	3417.0	7	2, 0

A weak system around 2900 A. has been reported in absorption by Vago and Barrow (*Nature, Lond.*, **157**, 77 (1946)).

SmO

Occurrence. Samarium salts in oxy-hydrogen flame.

Reference. G. Piccardi, *Rend. Accad. Linc.*, **21**, 589. (1935).

The following are the strongest heads :—

λ	<i>I</i>	λ	<i>I</i>
6570.1	6	6485.5	7
6557.2	8	6349.5	8
6533.5	9	6034.4	6
6510.9	10	5822.4	7

SnBr

Occurrence. Heavy-current discharge through flowing tin tetrabromide vapour.

Reference. W. Jevons and L. A. Bashford, *Proc. Phys. Soc.*, **49**, 554. (1937)†.

VIOLET SYSTEM, $\lambda\lambda 4255$ – 3709

Appearance. Degraded to the red.

Transition. ${}^2\Delta \rightarrow {}^2\Pi$, ground state.

Strong bands only :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
4196.5	6	0, 3 i	3820.8	6	0, 2 ii
4153.9	8	0, 2 i	3798.4	7	1, 2 ii
4112.1	10	0, 1 i	3785.8	7	0, 1 ii
4070.7	10	0, 0 i	3750.8	8	0, 0 ii
3833.7	6	1, 3 ii	3729.4	6	1, 0 ii

ULTRA-VIOLET SYSTEM, $\lambda\lambda 3428$ – 3021

Appearance. Degraded to shorter wave-lengths. Two progressions which look rather like sequences.

Transition. ${}^2\Sigma \rightarrow {}^2\Pi$, ground state.

Strong bands only :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3372.0	4	0, 4 i	3112.2	4	0, 4 ii
3344.6	5	0, 3 i	3089.2	5	0, 3 ii
3317.2	6	0, 2 i	3066.4	6	0, 2 ii
3290.4	7	0, 1 i	3043.6	7	0, 1 ii
3263.7	*	0, 0 i	3021.1	4	0, 0 ii

* Masked by Sn line 3262.33.

SnCl

There are three band systems in the ultra-violet, $\lambda\lambda 3910$ – 3486 , $\lambda\lambda 3405$ – 2830 and $\lambda\lambda 2450$ – 2250 ; there are also two regions of continuous spectrum, from $\lambda 4900$ to $\lambda 3950$ and in the far ultra-violet.

Occurrence. All systems have been obtained in absorption by strongly-heated SnCl_2 , and the first two band systems have been observed in emission from an uncondensed discharge through tin tetrachloride vapour.

References. W. Jevons, *P.R.S.*, **110**, 365. (1926)†.

W. F. C. Ferguson, *P.R.*, **32**, 607. (1929).

C. A. Fowler, *P.R.*, **62**, 141. (1942)†.

 $\lambda\lambda 3910$ – 3486 SYSTEM

Appearance. Degraded to red. Two strong sequences.

Transition. ${}^2\Delta \rightarrow {}^2\Pi$, ground state.

Heads of strong bands :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3786.3	2	3, 3 i	3511.2	1	3, 3 ii
3776.6	5	2, 2 i	3502.5	2	2, 2 ii
3767.3	8	1, 1 i	3494.7	8	1, 1 ii
3758.5	10	0, 0 i	3487.8	10	0, 0 ii

SnCl (*contd.*) $\lambda\lambda 3405\text{--}2830$ SYSTEM

Appearance. Degraded to shorter wave-lengths. Strong SnCl^{35} heads with weaker SnCl^{37} heads visible in a few bands.

Transition. ${}^2\Sigma \rightarrow {}^2\Pi$, ground state.

Heads of strong bands only :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3271.5	5	0, 2 i	3004.5	6	0, 1 ii
3234.4	7	0, 1 i	2973.4	8	0, 0 ii
3197.8	7	0, 0 i	2966.3	3	1, 1 ii
3154.5	7	1, 0 i	2959.3	5	2, 2 ii
3112.4	5	2, 0 i	2935.8	10	1, 0 ii
3105.2	4	3, 1 i	2899.4	7	2, 0 ii
3036.4	4	0, 2 ii	2893.0	5	3, 1 ii

 $\lambda\lambda 2450\text{--}2250$ SYSTEM

Appearance. Degraded to shorter wave-lengths.

Transition. Probably ${}^2\Pi \rightarrow {}^2\Pi$, ground state.

The following are the strongest bands in absorption :—

λ	<i>I</i>	v', v''
2307.4	5	0, 1
2288.9	9	0, 0
2268.6	10	1, 0
2248.9	8	2, 0

SnF

Occurrence. In absorption.

Appearance. Four band systems, all degraded to shorter wave-lengths, and two regions of continuous absorption.

Reference. F. A. Jenkins and G. D. Rochester, *P.R.*, 52, 1135. (1937)†.

The P heads of the strong bands are given below. No intensities are available, but the high-frequency components of the doublet systems (denoted by ii below) are stated to be the stronger.

SYSTEM A ${}^2\Sigma \leftarrow X {}^2\Pi$, GROUND STATE, $\lambda\lambda 3260\text{--}2660$

This is the strongest system. Close double-headed bands, separation about 1A.

λ	v', v''	λ	v', v''
3199.7	0, 1 i	2969.4	1, 2 ii
3141.2	0, 0 i	2927.9	0, 0 ii
3076.2	1, 0 i	2871.4	1, 0 ii
3020.7	0, 2 ii	2817.6	2, 0 ii
2978.2	0, 1 ii		

SYSTEM B ${}^2\Delta \leftarrow X {}^2\Pi$, $\lambda\lambda 2635\text{--}2556$

Close double-headed bands. System partly obscured by continuum.

λ	v', v''
2635.4	0, 1
2595.5	0, 0
2556.3	1, 0

SnF (*contd.*)**SYSTEM C** ${}^2\Pi \leftarrow X {}^2\Pi$, $\lambda\lambda 2350-2100$

This is a weak system of single-headed bands.

λ	v', v''
2348.2	1, 0 i
2222.8	0, 1 ii
2194.7	0, 0 ii
2162.5	1, 0 ii

SYSTEM D ${}^2\Delta \leftarrow X {}^2\Pi$, $\lambda\lambda 2300-2060$

A strong system of close double-headed bands.

λ	v', v''	λ	v', v''
2296.7	0, 1 i	2184.3	0, 1 ii
2266.3	0, 0 i	2157.1	0, 0 ii
2236.1	1, 1 i	2129.3	1, 0 ii

CONTINUA

E $\leftarrow X {}^2\Pi$, $\lambda 2500-2370$.

F $\leftarrow X {}^2\Pi$. In far ultra-violet below 2100 A.

SnH

4050 A SYSTEM

Occurrence. Obtained by Watson and Simon from a tin arc in hydrogen at 5 atmospheres pressure.

Appearance. Complex bands degraded to the red.

Transition. ${}^2\Delta \rightarrow {}^2\Pi$, ground state.

Reference. W. W. Watson and R. Simon, *P.R.*, **55**, 358. (1939).

With low dispersion, heads are observed at 4054 A. and 4447 A., followed by stronger heads at 4071 A. and 4466 A. The latter are shown to be complex by high dispersion.

${}^R Q_{1dc,cd}$	$R_{1dc,cd}$	Q_2	${}^R R_{12}$
4071.3	4071.8	4466.6	4466.0
4071.4	4070.8		

The band is assumed to be the (0, 0) band of the system.

6095 A SYSTEM

Under similar conditions Watson and Simon observed a band to longer wave-lengths with heads at 6095 A., 6063 A., and 6022 A., accompanied by a weaker band with a head at 6214 A. Further bands to the red and infra-red are mentioned but no details are given.

RED SYSTEM

Appearance. Watson and Simon in a later paper report further bands degraded to the red with prominent heads at 6745, 6892 and 7030 A. with a pile up of lines at 6931 A. These authors consider it probable that further bands lie to the infra red.

Transition. Probably ${}^2\Sigma \rightarrow {}^2\Pi$, ground state.

Reference. W. W. Watson and R. Simon, *P.R.*, **57**, 708. (1940).

SnO

Occurrence. In arcs and flames containing tin salts; Connelly used a high-tension discharge through a flame containing SnCl_4 vapour for the production of the main system, and Loomis and Watson used an arc at reduced pressure for their system. In absorption by Sharma.

References. F. C. Connelly, *Proc. Phys. Soc.*, **45**, 780. (1933)†.

F. W. Loomis and T. F. Watson, *P.R.*, **45**, 805. (1934).

D. Sharma, *Proc. Nat. Acad. Sci. India*, **A14**, 133. (1944).

The strongest system, A, lies in the violet and near ultra-violet, and two doubtful weaker systems B and C are also in the violet. Loomis and Watson's system is a little further to the ultra-violet.

MAIN SYSTEM A, $\lambda\lambda 4488-3072$

Appearance. Degraded to red.

Transition. $^1\Sigma' \rightarrow ^1\Sigma$, ground state.

The strong bands only are listed. Intensities on scale of 8.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3691.4	5	0, 3	3388.3	6	0, 0
3585.4	7	0, 2	3323.4	7	1, 0
3484.5	8	0, 1	3262.4	6	2, 0
3415.8	5	1, 1	3205.8	4	3, 0

SYSTEMS B and C

Degraded to red. Strong bands:—

System B			System C		
λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
4217.7	3	0, 2	4411.4	3	0, 2
4079.1	3	0, 1	4302.9	3	1, 2
3978.7	2	1, 1	4262.3	3	0, 1

LOOMIS AND WATSON'S SYSTEM

Appearance. Degraded to red.

Transition. To ground state.

Strong bands only are listed. Intensities I_e and I_a on a scale of 8 for emission and 10 for absorption, respectively.

λ	I_e	I_a	v', v''	λ	I_e	I_a	v', v''	λ	I_e	I_a	v', v''
3043.6	6		2, 6	2740.1	6	4	3, 2	2560.0	3	10	5, 0
2990.4	8		0, 4	2716.9	7	8	2, 1	2529.9	3	10	6, 0
2947.7	6		1, 4	2680.8	6	9	3, 1	2500.4	2	10	7, 0
2921.7	8	2	0, 3	2658.1	6	2	2, 0	2472.3	2	10	8, 0
2814.8	8	5	1, 2	2646.9	6	9	4, 1	2445.0	1	9	9, 0

Note added in proof. B. Eisler and R. F. Barrow (*Proc. Phys. Soc.*, **62**, 740 (1949)†) have extended Loomis and Watson's system and shown that v' should be raised one unit. All systems have been obtained in absorption. There may be a new system of bands, degraded to the red, $\lambda\lambda 2132, 2117, 2102, 2084, 2073, 2069, 2054, 2050, 2037$.

SnS

Three systems have been obtained in absorption, and two of these, B and C, have been observed by Barrow in a discharge tube.

References. G. D. Rochester, *P.R.S.*, **150**, 668. (1935)†.

D. Sharma, *Proc. Nat. Acad. Sci. India*, **A14**, 217. (1945)†.

SYSTEM A, $\lambda\lambda$ 4709–4183

Strongest bands, degraded to red, $\lambda\lambda$ 4505.3, 4430.7, 4337.7, 4248.4, 4183.2.

SYSTEM B, $\lambda\lambda$ 4033–3198

Degraded to the red. Strongest bands, $\lambda\lambda$ 3865.3, 3728.2, 3662.8, 3599.3, 3557.1, 3496.6, 3418.8, 3381.6.

SYSTEM C, $\lambda\lambda$ 3325–2700

Degraded to red. Strongest bands (intensity 10) from Sharma, 3163.9 (2, 4), 3116.8 (2, 3), 3089.1 (3, 3), 3062.4 (4, 3), 2992.6 (5, 2), 2967.7 (6, 2), 2902.1 (7, 1), 2879.2 (8, 1), 2735.8 (13, 0), 2715.9 (14, 0).

SnSe

Three band systems, A, B, and C, have been obtained in absorption by Walker *et al.*, and system C and a possible fourth system D have been obtained by Barrow and Vago in emission in a high-current-density discharge through the vapours of Sn and Se. The bands of all systems are degraded to the red. Many of the heads are rather diffuse because of isotope splitting.

References. J. W. Walker, J. W. Straley and A. W. Smith, *P.R.*, **53**, 140. (1938).

R. F. Barrow and E. E. Vago, *Proc. Phys. Soc.*, **55**, 326. (1943)†.

D. Sharma, *Proc. Nat. Acad. Sci. India*, **A14**, 224. (1945).

SYSTEM A

Strongest bands : $\lambda\lambda$ 5392.8 (1, 3), 5330.0 (2, 3), 5238.6 (2, 2).

SYSTEM B

Strongest bands, in absorption :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
4734.5	7	1, 5	4572.8	10	0, 2
4664.4	10	1, 4	4504.8	10	0, 1
4646.1	6	0, 3	4396.3	10	0, 0
4595.2	7	1, 3			

SYSTEM C

Strongest bands in emission, with our estimates of intensity from published spectrogram :—

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3963.7	7	0, 7	3770.9	9	0, 3	3620.2	8	2, 1
3914.1	8	0, 6	3739.2	10	1, 3	3591.6	10	3, 1
3865.1	8	0, 5	3694.1	9	1, 2	3563.5	9	4, 1
3817.7	9	0, 4	3664.0	9	2, 3	3536.3	8	5, 1

SnSe (contd.)**SYSTEM D**

The following bands have been observed in emission: $\lambda\lambda$ 3434.7, 3397.3, 3374.9, 3359.8, 3339.0, 3317.8, 3297.0, 3282.2, 3267.8, 3247.4, 3242.2, 3227.8, 3214.0, 3203.4, 3189.7, 3157.6, 3119.3, 3102.2; no intensities are available.

SnTe

Five systems of bands, A, B, C, D, and E, all degraded to the red, have been observed in absorption by Barrow and Vago, and two of these systems, D and E (referred to as A and B in Barrow's first paper), have been obtained in emission in an uncondensed discharge through a mixture of Sn, Te and Al vapours. Sharma has recently reported four more systems in absorption.

References. R. F. Barrow, *Proc. Phys. Soc.*, **52**, 380. (1940)†.

R. F. Barrow and E. E. Vago, *Proc. Phys. Soc.*, **56**, 78. (1944)†.

D. Sharma, *Proc. Nat. Acad. Sci. India*, **A14**, 232. (1945).

No intensity estimates are available, but the following bands appear prominently in the published spectrograms.

SYSTEM A

λ	v', v''	λ	v', v''	λ	v', v''
6236.2	0, 3	5916.0	2, 1	5653.7	5, 0
6167.6	1, 3	5854.8	3, 1	5598.8	6, 0
6071.6	1, 2	5795.8	4, 1	5545.5	7, 0
6007.3	2, 2	5710.1	4, 0		

SYSTEM B

λ	v', v''	λ	v', v''	λ	v', v''
5165.7	0, 4	4975.6	1, 2	4807.7	3, 1
5098.6	0, 3	4968.5	0, 1	4798.5	2, 0
5040.0	1, 3	4912.8	1, 1	4748.5	3, 0
5033.0	0, 2	4859.2	2, 1	4699.4	4, 0

SYSTEM C

λ	v', v''	λ	v', v''	λ	v', v''
4738.8	1, 2	4580.0	2, 0	4493.1	4, 0
4672.0	0, 0	4546.1	4, 1	4451.1	5, 0
4634.7	2, 1	4535.8	3, 0	4410.5	6, 0
4589.6	3, 1				

SYSTEM D

λ	v', v''	λ	v', v''	λ	v', v''
4189.5	0, 6	4058.8	0, 3	3893.3	3, 1
4145.3	0, 5	3988.5	1, 2	3854.0	3, 0
4101.3	0, 4	3920.3	2, 1	3827.9	4, 0

SYSTEM E

λ	v', v''
3765.0	0, 4
3728.9	0, 3
3693.9	0, 2

SnTe (*contd.*)

Sharma's systems lie in the regions

- F. $\lambda\lambda 3666-3456$
- G. $\lambda\lambda 3512-3298$
- H. $\lambda\lambda 3309-3165$
- K. $\lambda\lambda 2400-2100$

Each consists of a fairly large number of closely-spaced bands, all degraded to the red.

SrBr

There are two systems attributed to SrBr, in the red and in the violet.

RED SYSTEM

Occurrence. In absorption and when strontium bromide is introduced into a flame. They do not appear strongly in an arc.

Appearance. Close marked sequences; the bands appear to be degraded to shorter wave-lengths under low dispersion.

Transition. Probably ${}^2H \rightarrow {}^2\Sigma$, ground state.

References. K. Hedfeld, *Z.P.*, **68**, 610. (1931).

O. H. Walters and S. Barratt, *P.R.S.*, **118**, 120. (1928).

The following list of measurements is compiled from the above sources. Intensities I_a and I_f are for absorption and emission in a flame respectively.

λ	I_a	I_f	Sequence
6924	0		
6800.2	10		
6763.6		0	0, 1 i
6666.7	10	10	0, 0 i
6605.4		0	0, 1 ii
6572.4		0	1, 0 i
6513.0	5	10	0, 0 ii
6422.8		0	1, 0 ii

VIOLET SYSTEM

Occurrence. In absorption and in a flame.

Appearance. Close sequences which appear to be degraded to longer wave-lengths with small dispersion.

References. O. H. Walters and S. Barratt, *P.R.S.*, **118**, 120. (1928).

C. M. Olmsted, *Z. wiss., Photogr.*, **4**, 255. (1906).

The following measurements are by Walters and Barratt. Intensities I_a and I_f are for absorption and emission in a flame, the latter being by Olmsted.

λ	I_a	I_f	λ	I_a	I_f
4186	0	1	4053	10	6
4146	4	3	4019	2	3
4129	1	2	3992	0	1
4108	9	6	3945	5	
4090	3	3	3909	5	
4073	2	3			

SrCl

Occurrence. When strontium chloride is introduced into an arc or flame. Also in absorption.

References. K. Hedfeld, *Z.P.*, **68**, 610. (1931)†.

A. E. Parker, *P.R.*, **47**, 349. (1935).

There are two strong systems, in the red and violet respectively. Parker also reports some weaker bands in the red and orange.

RED SYSTEM, $\lambda\lambda 6752-6232$

Appearance. Degraded to violet. Close sequences.

Transition. Perhaps $A \ ^2\Pi \rightarrow \ ^2\Sigma$, ground state.

Heads of strong sequences :—

λ	I	Sequence *
6755.6	3	0, 1 P_1
6744.7	5	Q_1
6619.9	5	0, 0 P_1
6613.7	10	Q_1
6482.9	4	1, 0 Q_1 and 0, 1 Q_2
6362.4	5	0, 0 P_2
6358.7	10	Q_2
6239.3	2	1, 0 Q_2

* The vibrational analyses made by Hedfeld and by Parker do not correspond exactly.

VIOLET SYSTEM, $\lambda\lambda 4136-3852$

Appearance. Degraded to red.

Transition. Perhaps $B \ ^2\Pi \rightarrow \ ^2\Sigma$, ground state.

No intensities given. The following are the Q heads of sequences, the R heads, which are presumably weaker, lie about 1 A to the violet :—

λ	Description
4009.4	Q_1 head of (1, 2) band, the first observed member of the (0, 1) sequence.
3983.4	Q_2 head of (1, 2) band.
*3961.6	Q_1 head of (0, 0) band and sequence.
3937.1	Q_2 " " " " "
3918.3	Q_1 " (1, 0) " " "
3894.0	Q_2 " " " " "

* Strongest head.

WEAKER BANDS. These may be due to CaCl.

Heads of sequences :—

λ	Degraded
6462.0	V
6184.8	V
6070.3	R
6068.1	R
5934.1	R

SrF

Seven systems have been observed in absorption by heated SrF₂ vapour by Fowler, and three of these, the A system in the red, the B system in the yellow, and the C system, are well known in emission when SrF₂ is introduced into a carbon arc or flame.

References. S. Datta, *P.R.S.*, **99**, 436. (1921)†.
 R. C. Johnson, *P.R.S.*, **122**, 161. (1929).
 A. Harvey, *P.R.S.*, **133**, 336. (1931)†.
 C. A. Fowler, *P.R.*, **59**, 645. (1941)†.

RED SYSTEM, λλ6870–6283

A ²Π → ²Σ, ground state. Marked sequences. Appearance best shown by Datta's photographs.

Strongest heads of sequences :—

λ	I	Sequence
6655.6 V	7	0, 0 P ₁₂
6632.7 V	10	0, 0 Q ₁₂
6527.6 V	7	0, 0 P ₂
6512.0 V	10	0, 0 Q ₂
6419.0 V	8	1, 0
6394.7 R		
6306.1 V	8	1, 0
6283.1 R		

YELLOW SYSTEM, λλ5852–5021

B ²Σ → ²Σ, ground state. Degraded to red.

(0, 0) sequence R head λ 5779.5

 " " Q ,, 5772.0

(1, 0) sequence, evenly spaced bands between λ5622 and 5670.

C SYSTEM, λλ3795–3646

C ²Π → ²Σ, ground state. Degraded to red. Heads of sequences at λλ3646.3 and 3712.4.

D SYSTEM, λλ3592–3345

D ²Σ → ²Σ, ground state. Degraded to shorter wave-lengths. Strongest bands in absorption (calculated from Fowler's formula) :—

λ	I	v', v''
3529.8	9	0, 0
3522.9	10	1, 1
3517.1	8	2, 2
3457.2	7	2, 1
3451.6	7	3, 2

E SYSTEM, λλ3218–3052

E ²Π → ²Σ, ground state. Degraded to shorter wave-lengths. Strongest bands in absorption :—

SrF (*contd.*)

λ	I	v', v''
3218.2	5	0, 1
3167.6	10	0, 0
3112.6	7	1, 0
3106.4	6	2, 1

F SYSTEM, $\lambda\lambda 3069-2916$

F ${}^2\Sigma \rightarrow {}^2\Sigma$, ground state. Degraded to shorter wave-lengths. Strongest bands in absorption :—

λ	I	v', v''
3088.3	6	0, 1
3041.5	8	0, 0
2987.8	10	1, 0
2978.1	7	2, 1
2929.6	7	3, 1

G SYSTEM, $\lambda\lambda 2915-2775$

G ${}^2\Pi \rightarrow {}^2\Sigma$, ground state. Degraded to shorter wave-lengths. Strongest bands in absorption :—

λ	I	v', v''
2873.2	10	0, 0
2826.7	8	1, 0
2821.0	5	2, 1
2782.0	6	2, 0

SrH

Reference. W. W. Watson and W. R. Fredrickson, *P.R.*, 39, 765. (1932).

7508 A. SYSTEM, ${}^2\Pi \rightarrow {}^2\Sigma$, GROUND STATE

Bands degraded to the violet. Obtained from strontium arc in hydrogen.

v', v''	Heads
0, 0	7508 P ₁
	7505 ^P Q ₁₂
	7348.0 ^Q P ₂₁
	7346.7 Q ₂

7020 A. SYSTEM, ${}^2\Sigma \rightarrow {}^2\Sigma$, GROUND STATE

Bands degraded to the violet. Obtained in strontium arc in hydrogen.

v', v''	Heads
0, 0	7018.1 P ₁
	6984.7 P ₂

OTHER SYSTEMS ?

Watson and Fredrickson note that in their experiments a dense grouping of lines appeared in the yellow-green and small groups at around 5800 A.

SrI

Band systems have been observed in the red and violet by Walters and Barratt, who also report three faint bands in the ultra-violet.

References. O. H. Walters and S. Barratt, *P.R.S.*, 118, 120. (1928)†.

C. M. Olmsted, *Z. wiss. Photogr.*, 4, 255. (1906).

SrI (*contd.*)

RED SYSTEM

Occurrence. In absorption. Olmsted also speaks of bands in the orange in a flame source; these may be the same.

Appearance. Degraded to the violet.

The following measurements are by Walters and Barratt:—

λ	I	λ	I
7094.0	2	6767.8	10
7011.0	10	6691.5	8
6930.2	10	6662.3	8
6847.7	10	6177.3	4

VIOLET SYSTEM

Occurrence. In absorption, when strontium iodide is introduced into a flame, and probably in arc sources.

Appearance. Degraded to the red. Marked close sequences. The following measurements of the heads of the sequences are by Walters and Barratt. Intensities I_a and I_f are for absorption and emission in a flame respectively, the latter being by Olmsted.

λ	I_a	I_f	λ	I_a	I_f
4482	0	4	4339	2	4
4447	4	5	4307	6	6
4412	10	6	4276	1	2
4381	1	4			

ULTRA-VIOLET

Three weak bands $\lambda\lambda 3439, 3406, \text{ and } 3378$, degraded to shorter wave-lengths, were observed in absorption.

SrO

Occurrence. When strontium salts are introduced into a carbon arc burning in air or into a flame.

Appearance. Degraded to red. Two systems, in the blue, and in the ultra-violet.

Reference. P. C. Mahanti, *P.R.*, 42, 609. (1932)†.

Only the strong bands listed by Mahanti are given below. The intensities are on a scale of 6.

BLUE SYSTEM

λ	I	v', v''	λ	I	v', v''
4692.7	5	2, 7	4399.6	6	0, 3
4672.6	4	1, 6	4302.7	4	1, 3
4652.4	3	0, 5	4281.0	5	0, 2
4564.8	5	2, 6	4189.1	4	1, 2
4544.1	5	1, 5	4167.2	5	0, 1
4523.3	4	0, 4	4058.0	3	0, 0
4463.3	4	3, 6	3975.4	3	1, 0
4420.9	4	1, 4	3897.1	3	2, 0

SrO (*contd.*)

ULTRA-VIOLET SYSTEM

λ	I	v', v''
3586.9	3	0, 1
3525.4	3	1, 1
3503.8	6	0, 0
3445.2	4	1, 0
3389.8	4	2, 0
3337.5	3	3, 0

INFRA-RED SYSTEM

Appearance. Degraded to the red.

References. K. Mahla, *Z.P.*, **81**, 625. (1933)†.

G. Almkvist and A. Lagerqvist, *Nature, Lond.*, **164**, 665. (1949)

Almkvist and Lagerqvist give the analysis,

λ	v', v''	λ	v', v''
10437.1	1, 3	8722.5	2, 1
10426.2	0, 2	8700.0	1, 0
9776.1	0, 1	8257.8	2, 0
9195.8	0, 0		

Mahla also gives heads at $\lambda\lambda 7852.8$ and 7484.3 .

ORANGE-RED SYSTEM, 7000–5300 Å.

There is a strong patch of emission around 6000 Å. which occurs in flames, arcs and heavy-current discharges containing SrO. The assignment to SrO is probable, but not certain (Mahanti attributes them to Sr₂). The band around 6000 shows weak heads, degraded to the violet, for which Dr. R. F. Barrow has supplied the following measurements: $\lambda\lambda 6114.2$, 6111.9 , 6109.9 , 6107.5 , 6101.3 , 6096.5 , 6090.2 , 6085.1 , 6077.2 . There is a similar band around 6200–6900 with the following heads: $\lambda\lambda 6884.5$, 6875.6 , 6867.9 , 6861.4 .

TaO

Reference. C. C. Kiess and E. Z. Stowell, *Nat. Bur. Stand. J. Res.*, **12**, 459. (1934).

In studying the line spectrum of tantalum, as obtained from an arc between metallic poles, Kiess and Stowell record a band spectrum probably due to TaO. The bands are degraded to longer wave-lengths; the following are the strongest bands:—

λ	I	λ	I	λ	I
5567.0	4	4679.5	3	4006.2	4
5385.2	3?	4651.9	3	3896.4	4
4901.6	3?	4154.4	7?	3747.2	4
4810.4	4	4092.1	3?	3625.7	4

Further bands were observed in the infra-red.

Te₂

MAIN SYSTEM

Occurrence. Absorption by tellurium vapour, fluorescence, and emission (presumably in discharge tubes).

Appearance. Degraded to the red. An extensive system consisting of a large number of bands.

Te₂ (*contd.*)

References. B. Rosen, *Z.P.*, 43, 69. (1927).
E. Olsson, *Z.P.*, 95, 215. (1935).

The following measurements of the strong bands are by Olsson, with his vibrational quantum numbers. The intensities are from Rosen and are for absorption. The band heads are complex because of the isotope effect. Olsson's measurements are for the strongest head, $\text{Te}^{128}\text{Te}^{128} + \text{Te}^{130}\text{Te}^{126}$. Rosen's measurements are systematically lower than Olsson's by an amount increasing from zero at the red end of the system to 5 Å at the violet end, this probably being largely due to the isotope effect.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
4849.0	3	1, 7	4448.8	3	5, 2	4211.8	3	10, 0
4793.6	3	1, 6	4435.7	3	7, 3	4202.9	4	12, 1
4740.7	3	1, 5	4418.3	3	6, 2	4185.7	3	11, 0
4703.5	3	2, 5	4388.4	3	7, 2	4159.6	4	12, 0
4686.7	3	4, 6	4369.4	3	6, 1	4134.5	4	13, 0
4666.8	3	3, 5	4358.9	4	8, 2	4110.0	5	14, 0
4649.4	3	2, 4	4341.3	3	7, 1	4082.8	5	15, 0
4617.2	3	6, 6	4330.4	4	9, 2	4060.6	5	16, 0
4581.0	4	4, 4	4312.5	3	8, 1	4040.2	5	17, 0
4564.9	3	6, 5	4302.2	4	10, 2	4018.2	5	18, 0
4548.1	4	5, 4	4284.5	4	9, 1	3996.8	5	19, 0
4530.0	4	4, 3	4256.8	4	10, 1	3976.0	5	20, 0
4498.0	4	5, 3	4238.1	3	9, 0	3956.0	4	21, 0
4466.4	3	6, 3	4230.2	4	11, 1	3913.5	4	22, 0

OTHER SYSTEMS

References. M. Désirant and A. Minne, *C.R. Acad. Sci. Paris*, 202, 1272. (1936).
Choong Shin-Piaw, *C.R. Acad. Sci. Paris*, 203, 239. (1936); and *Ann. Phys. Paris*, 10, 173. (1938).

R. Migeotte, *Mem. Soc. Roy. Sci. Liège*, 5, 1. (1942).

Désirant and Minne record bands in the visible in a high-frequency discharge, analysed into two systems with origins of the (0, 0) bands at $\nu = 18,900$ and $16,370$.

Choong Shin-Piaw has studied the spectrum in the ultra-violet and gives a formula for bands in the region $\lambda\lambda 2495-1975$. Migeotte has arranged absorption bands in this region into four systems.

TeBr₂

Diffuse bands, degraded to the red, in the region $\lambda\lambda 6500-5300$ have been observed in absorption.

Reference. - M. Wehrli, *Helvetica Phys. Acta*, 9, 208. (1936)†.

Strongest bands :—

λ	<i>I</i>
6037	6
5957	7
5888	8
5816	9
5744	9
5676	8

TeCl₂

VISIBLE SYSTEM

Diffuse bands, degraded to the red, in the region $\lambda\lambda 6400-4725$ have been observed in absorption.

Reference. M. Wehrli, *Helvetica Phys. Acta.*, **9**, 208. (1936)†.

Strongest bands :—

λ	<i>I</i>	λ	<i>I</i>
5758.6	3	5443.4	7
5720.0	2	5353.6	6
5656.1	3	5267.5	5
5634.3	3	5183.5	4
5536.4	5	5103	4

ULTRA-VIOLET SYSTEM

Bands 2050–2300 A. in absorption. Degraded to shorter wave-lengths.

Reference. P. Müller and M. Wehrli, *Helvetica Phys. Acta.*, **15**, 307. (1942).

Strongest bands : $\lambda\lambda 2079.6, 2084.6, 2105.4, 2111.9, 2118.6, 2138.6$.

TeO

Occurrence. Discharge through tellurium vapour and oxygen in heated silica tube. Also in absorption.

Appearance. Degraded to red.

Reference. Choong Shin-Piaw, *Ann. Phys. Paris*, **10**, 173. (1938)†.

Strong bands :—

λ	<i>I</i>	<i>v', v''</i>	λ	<i>I</i>	<i>v', v''</i>	λ	<i>I</i>	<i>v', v''</i>
3818.8	10	0, 4	3607.0	8	0, 2	3463.8	7	1, 1
3767.2	5	1, 4	3560.6	8	1, 2	3422.2	7	2, 1
3710.0	10	0, 3	3517.2	6	2, 2	3382.9	6	3, 1
3661.3	8	1, 3	3507.5	5	0, 1	3345.6	6	4, 1

TeO₂

Reference. As TeO.

A complex system of diffuse bands has been observed in absorption 4000–3200 A. The following are the strongest bands : $\lambda\lambda 3960.1, 3942.7, 3922.8, 3891.1, 3799.9, 3772.9, 3771.0, 3706.4, 3617.8, 3590.8$.

Note added in proof. J. Duchesne and B. Rosen (*J. Chem. Phys.*, **15**, 631 (1947)) have listed about 88 absorption bands between 4555 and 3026 A. Their values, for band maxima, show practically no agreement with those above. They also list 12 bands $\lambda\lambda 2650-2450$.

TiCl

Occurrence. Discharge tubes (including high-frequency discharge) containing flowing titanium chloride, TiCl₄, vapour.

Appearance. Degraded to shorter wave-lengths. A strong close sequence with head at 4192 A.

Reference. K. R. More and A. H. Parker, *P.R.*, **52**, 1150. (1937).

TiCl (*contd.*)

In the following table all the observed heads of the (0, 0) band and the strongest (second) head of the other strong bands are given :—

λ	I	v', v''
4199.5	1	0, 0
4192.7	10	
4189.1	4	
4188.0	8	
4184.5	6	
4181.8	5	
4183.1	9	1, 1
4172.2	9	2, 2
4160.3	6	3, 3
4106.9	3	1, 0

There are also weaker bands in the regions 4050–4000 A., 3935–3840 A., 3750–3720 A., but no measurements are available.

TiO

Three strong systems, in the red, the orange and the blue-green, have been attributed to this molecule. See Plate 8.

Occurrence. In arcs and furnaces containing titanium dioxide and in discharge tubes containing titanium chloride and oxygen. The bands are a prominent feature of the spectra of M-type stars.

RED SYSTEM, γ

Appearance. Degraded to longer wave-lengths. The bands have rather widely-spaced triple heads, but the appearance is confused by overlapping.

Transition. A ${}^3\Sigma \rightarrow X {}^3\Pi$, probably ground state.

Reference. F. Lowater, *Proc. Phys. Soc.*, 41, 557. (1929)†.

The following are the strong heads as listed by Lowater. Intensities have been reduced to a scale of 10.

λ	I	v', v''	λ	I	v', v''
7948.6	7	4, 5 Q _b	7197.7	7	1, 1 R _c , 2, 2 R _a
7907.3	5	4, 5 Q _a , 3, 4 R _c	7159.0	5	1, 1 R _b
7861.0	5	3, 4 R _b	7125.6	10	0, 0 R _c , 1, 1 R _a
7828.0	8	2, 3 R _c , 3, 4 Q _a	7087.9	9	0, 0 R _b
7820.1	7	3, 4 R _a	7054.5	7	0, 0 R _a
7705.2	7	1, 2 R _b	6852.3	5	4, 3 R _a
7672.1	8	0, 1 R _c , 1, 2 Q _a	6719.3	5	2, 1 R _a , 1, 0 Q _c
7666.4	5	1, 2 R _a	6714.4	5	1, 0 R _c
7628.1	7	0, 1 R _b	6681.1	5	1, 0 R _b
7589.6	7	0, 1 R _a	6651.5	4	1, 0 R _a
7269.0	5	2, 2 R _c , 3, 3 R _a	6215.2	5	6, 3 Q _c
7219.4	5	1, 1 Q _c			

ORANGE SYSTEM, β

Appearance. Degraded to the red. A single sequence of double-headed bands.

Transition. Uncertain. The appearance is suggestive of a singlet system, but efforts have been made to relate it to the ${}^3\Pi$ ground state.

TiO (*contd.*)

Reference. F. Lowater, *Proc. Phys. Soc.*, **41**, 557. (1929)†.

The following are the strongest heads :—

λ	I	v', v''
5694.4	3	3, 3 R
5661.6	6	2, 2 R
5629.3	6	1, 1 R
5603.8	3	0, 0 Q
5597.8	7	0, 0 R

BLUE-GREEN SYSTEM, α

Appearance. Degraded to the red ; close triple-headed bands forming fairly obvious sequences.

Transition. ${}^3\Pi \rightarrow {}^3\Pi$, ground state.

References. A. Fowler, *P.R.S.*, **79**, 509. (1907)†.

A. Christy, *P.R.*, **33**, 701. (1929).

First heads of strong bands :—

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
6214.9	8	2, 5	5448.3	7	0, 1	4848.0	3	4, 2
6159.1	10	1, 4	5240.5	5	1, 1	4804.3	5	3, 1
5861.7	4	2, 4	5166.9	7	0, 0	4761.2	5	2, 0
5810.0	4	1, 3	5050.3	3	3, 2	4626.1	4	4, 1
5758.5	4	0, 2	5002.7	3	2, 1	4584.1	3	3, 0
5497.0	5	1, 2	4954.5	6	1, 0	4462.1	3	4, 0

TlBr**MAIN SYSTEM**

Occurrence. In uncondensed discharge ; also in absorption.

Appearance. Degraded to red.

Transition. (Hund's case *c*) $1 \rightarrow {}^1\Sigma$, ground state.

References. K. Butkow, *Z.P.*, **58**, 232. (1929)†.

H. G. Howell and N. Coulson, *Proc. Phys. Soc.*, **53**, 706. (1941)†.

Strongest bands (for isotope TlBr⁷⁹) from Butkow. Intensities in absorption.

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
3556.5	3	1, 6	3486.4	7	1, 3	3440.9	6	1, 1
3532.9	4	1, 5	3475.3	8	0, 2	3429.6	10	0, 0
3509.7	5	1, 4	3463.6	8	1, 2	3418.2	9	1, 0
3498.4	5	0, 3	3452.4	9	0, 1	3408.2	6	2, 0

3950 A. SYSTEM

Occurrence. Uncondensed discharge through TlBr vapour.

Appearance. Degraded to red.

Transition. From a highly excited state to upper level of main system.

Reference. H. G. Howell and N. Coulson, *Proc. Phys. Soc.*, **53**, 706. (1941)†.

Strong bands :—

λ	I	v', v''
3973.8	6	0, 2
3960.2	8	0, 1
3945.2	10	0, 0
3933.7	8	1, 0

TIBr (contd.)

Note added in proof. P. T. Rao (*Indian J. Phys.*, **23**, 265 (1949)) suggests that there may be a new system 3980–3800 Å. and that the v' numbering for some bands of the main system may be in error.

TICI

In absorption thallium chloride vapour shows a strong band system between 3575 and 3176 Å. and two strong narrow regions of continuum centered at 3110 and 2520 Å. The band system has been observed in absorption as an impurity in other substances, especially in cadmium. It is also obtained in emission in a discharge tube (including a high-frequency discharge) through TICI vapour. Miescher has also reported another band system in the violet in emission in a discharge tube.

References. H. G. Howell and N. Coulson, *P.R.S.*, **166**, 238. (1938)†.
E. Miescher, *Helv. Phys. Acta.*, **14**, 148. (1941)†.
P. T. Rao, *Curr. Sci.*, **18**, 42. (1949).

MAIN SYSTEM, $\lambda\lambda 3575\text{--}3176$

Appearance. Degraded to the red. Strong (0, 0) sequence. The bands show isotope effect.

The following are the heads of the more abundant isotope TICI³⁵ for the strong bands as obtained in emission by Howell and Coulson:—

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
3372.0	2	3, 7	3299.7	7	2, 4	*3240.6	9	2, 2
3360.4	1	2, 6	3289.6	8	1, 3	*3230.4	10	1, 1
3341.4	2	3, 6	3270.0	7	2, 3	*3220.9	10	0, 0
3329.9	2	2, 5	*3263.6	2	4, 4	3201.3	2	1, 0
3323.5	3	4, 6	3259.9	8	1, 2	*3193.4	1	3, 1
3319.6	3	1, 4	*3250.8	7	0, 1	*3182.6	2	2, 0

* Relatively strong in absorption.

VIOLET SYSTEM

Appearance. A complex system of bands, strongest in the region 4120–4050 Å., with heads degraded in either direction.

Strongest heads from Miescher; letters R, V and M denote degraded to red, violet, or maximum of headless structure:—

λ	I	λ	I	λ	I	λ	I
4244.6 R	6	4108.3 R	10	4060 M	10	4021 M	6
4223.6 R	8	4096.8 R	8	4051 M	8	4015.2 R	5
4218.0 R	6	4088.7 V	6	4045.6 M	9	3991.9 R	4
4210.7 V	6	4086.6 R	8	4038.4 R	7	3972 M	4
4182 V	5	4085.9 V	10	4025 M	5	3947.5 R	4

TIF

Three systems have been obtained in absorption in thallium fluoride vapour, and the first two of these have been observed in emission in a high-frequency discharge.

Reference. H. G. Howell, *P.R.S.*, **160**, 242. (1937)†.

SYSTEM $^3\text{I} \rightarrow ^1\Sigma$, $\lambda\lambda 3105\text{--}2809$

Bands degraded in either direction. The following are the strongest heads, with the direction of degradation indicated by R (red) and V (violet).

TIF (*contd.*)

λ	I	v', v''	λ	I	v', v''	λ	I	v', v''
2924.7 V	5	1, 3	2882.0 V	6	0, 1	2843.5 V	10	0, 0
2921.3 V	5	0, 2	2852.2 V	9	2, 2	2818.4 R	5	3, 2
2886.0 V	6	1, 2	2848.0 V	10	1, 1	2810.6 V	7	1, 0

SYSTEM $^30^+ \rightarrow ^1\Sigma^+$, $\lambda\lambda 2808-2668$

Degraded to red. Close double-headed bands:—

λ	I	v', v''	λ	I	v', v''
2759.7	7	1, 2	2724.9	10	1, 1
2748.1	6	0, 1	2713.7	10	0, 0
2737.1	9	2, 2	2690.8	3	1, 0

SYSTEM $^1\Pi \rightarrow ^1\Sigma$, $\lambda\lambda 2347-2198$

Degraded to the red:—

λ	I	v', v''	λ	I	v', v''
2250.4	4	1, 3	2221.0	9	0, 1
2244.3	5	0, 2	2203.9	8	1, 1
2227.0	8	1, 2	2198.0	10	0, 0

TIH

Several band systems were observed by Grundström and Valberg when thallium metal was heated with hydrogen in a furnace and when an arc between thallium and copper poles was run in hydrogen at about 500 mm. pressure. The bands are not yet completely systematised.

Reference. B. Grundström and P. Valberg, *Z.P.*, **108**, 326. (1938)†.

B \rightarrow A SYSTEM

v', v''	Origins
0, 0	5706.2
0, 1	6180.9

C \rightarrow A SYSTEM. Degraded red.

v', v''	Origins	R Heads
0, 1	5903.8	5895.2
1, 2	5914.4	5911.7
0, 2	6394.7	6382.9
0, 3	6952.8	6935.9

D \rightarrow A SYSTEM. Degraded red.

v', v''	Origins	R Heads
0, 1	5742.7	5739.2
1, 2	5772.3	—
0, 2	6206	—
1, 3	6223.2	6220.2
0, 3	6730.6	6725.0
1, 4	6729	—
0, 4	7327	7320

TIH (*contd.*)

E → A SYSTEM. Degraded red.

v', v''	Origins	R Heads
0, 2	6058·6	6055·2
1, 3	6062·4	—
0, 3	6557·4	6553·2

TII

Occurrence. In absorption by thallium iodide vapour.*Appearance.* Diffuse headless bands.*Reference.* K. Butkow, *Z.P.*, **58**, 232. (1929)†.

The following are the bands as listed by Butkow. No intensities are available, but from the reproduction it appears that the shorter wave-length bands are the stronger.

λ 3808, 3836, 3896, 3933, 3967, 4000, 4030, 4062, 4092, 4120, 4152, 4181 and 4211.

Note added in proof. P. T. Rao and K. R. Rao (*Indian J. Phys.*, **23**, 185 (1949)†) have obtained the system in emission in a high-frequency discharge. They have made a vibrational analysis and suggest that the transition is $^3\Pi_1 \rightarrow ^1\Sigma^+$. Bands in the violet are degraded to the red. Others are headless or diffuse. Of about 200 bands between 5300 and 3800 listed in this complex system, the following are given as strongest, λ 4620·8, 4591·3, 4557·1, 4511·6, 4477·9, 4422·6, 4342·6, 4315·9, 4269·7, 4213·3, 4113·2, 4088·8, 3900·8 (1, 2) and 3877·9 (0, 0).

There is also a weaker system of 25 bands 3680–3600 Å.

VO

Occurrence. In the flame surrounding arc containing vanadium metal or oxide.*Appearance.* Degraded to red. Double-headed, separation between R and Q heads about 0·8 Å.*Transition.* Probably $^2A \rightarrow ^2A$.*Reference.* P. C. Mahanti, *Proc. Phys. Soc.*, **47**, 433. (1935)†.

R heads of strong bands :—

λ	I	v', v''
6532·8	6	1, 3
6477·8	6	0, 2
6086·4	8	0, 1
5736·7	10	0, 0
5517·3	5	2, 1
5469·3	9	1, 0

WO

Occurrence. High-tension arc between tungsten electrodes in air.*Appearance.* A complex system of single-headed bands degraded to the red.

The following are rough measurements by Foster and Gaydon of the strong heads. The system has not been analysed and is attributed to WO on experimental evidence only.

WO (contd.)

λ	I	λ	I	λ	I
5396	3	4709.4	10	4414	5
5338	3	4609	8	4395	4
5210	5	4590.5	8	4338.5	5
4932	3	4562	4	4313	4
4903	3	4523	5	4284	4
4824	6	4473.5	5	4271.0	4
4806	9	4460	5	4110.5	2

YO

Occurrence. In arc containing yttrium salts.

References. L. W. Johnson and R. C. Johnson, *P.R.S.*, 133, 207. (1931).
W. F. Meggers and J. A. Wheeler, *Bur. Stand. J. Res.*, 6, 239. (1931)†.

ORANGE SYSTEM

Appearance. Degraded to the red. Long sequences.

Transition. ${}^2\Pi \rightarrow {}^2\Sigma$, ground state.

The following measurements of the strong heads at the beginnings of the main sequences are from Johnson and Johnson :—

λ	I	v', v''	λ	I	v', v''
5697.8	5	1, 0 i Q	5939.1	8	0, 0 i R
5713.9	6	2, 1 i Q	5956.4	7	1, 1 i R
5730.2	7	3, 2 i Q	5972.2	10	0, 0 i Q
5747.0	8	4, 3 i Q	5987.7	10	1, 1 i Q
5764.3	7	5, 4 i Q	6003.6	10	2, 2 i Q
5842.0	4	1, 0 ii Q	6096.8	8	0, 0 ii R
5858.9	5	2, 1 ii Q	6114.8	7	1, 1 ii R
5876.2	4	3, 2 ii Q	6132.1	10	0, 0 ii Q
5912.3	6	5, 4 ii Q	6148.4	10	1, 1 ii Q
5931.1	5	6, 5 ii Q	6165.1	10	2, 2 ii Q

BLUE-GREEN SYSTEM

Appearance. Degraded to the red. Close double-headed bands, separation about 0.8 Å.

Transition. ${}^2\Sigma \rightarrow {}^2\Sigma$, ground state.

The following measurements of the first heads of the strong bands are by Johnson and Johnson :—

λ	I	v', v''
5077.9	4	2, 3
5049.7	5	1, 2
5024.2	6	0, 1
4841.9	7	1, 1
4817.4	10	0, 0
4649.2	9	1, 0

Zn₂

References. H. Hamada, *Phil. Mag.*, **12**, 50. (1931)†.

J. M. Walter and S. Barratt, *P.R.S.*, **122**, 201. (1929).

Hamada has studied the emission by zinc in a hollow cathode. The zinc lines, especially $\lambda\lambda 2139$ and 3076 are broadened and show patches of continua and flutings attributed to incipient formation of Zn₂ molecules.

Walter and Barratt observe a diffuse band in absorption at about 3050 \AA .

ZnBr

References. K. Wieland, *Helv. Phys. Acta.*, **2**, 46. (1929).

J. M. Walter and S. Barratt, *P.R.S.*, **122**, 201. (1929).

E. Oeser, *Z.P.*, **95**, 699. (1935).

H. G. Howell, *P.R.S.*, **182**, 95. (1943).

VISIBLE SYSTEM $\lambda\lambda 8470-3300$

Occurrence. Low pressure discharges (including high-frequency) with ZnBr₂.

Appearance. Crowded bands degraded to the red on a continuum with pronounced intensity maximum at $\lambda 8300$. In the short wave region, at about $\lambda 3800$, the bands are very faint but a partial resolution into rotational lines can be seen.

Transition. Probably ${}^2\Sigma \rightarrow {}^2\Sigma$, ground state.

ULTRA-VIOLET BANDS $\lambda\lambda 3113-3028$

Occurrence. A number of bands, degraded to the red, has been observed in this region by Walter and Barratt in absorption.

Transition. Probably ${}^2\Pi \rightarrow {}^2\Sigma$, ground state.

Strongest heads:—

λ	I	v', v''
3110	4	0, 0
3102	2	
3071	4	0, 0
3068	3	
3064	2	

ZnBr₂

No bands due to ZnBr₂ are known. Emission bands previously ascribed to this molecule by Wieland are attributed to ZnBr. In absorption only continuous spectra have been observed (E. Oeser, *Z.P.*, **95**, 699 (1935)).

ZnCl

References. K. Wieland, *Helv. Phys. Acta.*, **2**, 46. (1929).

J. M. Walter and S. Barratt, *P.R.S.*, **122**, 201. (1929).

S. D. Cornell, *P.R.*, **54**, 341. (1938).

VISIBLE SYSTEM $\lambda\lambda 8650-3200$

Occurrence. ZnCl₂ in low-pressure discharge tubes (Wieland).

Appearance. Crowded bands degraded to the red on a continuum with intensity maximum at $\lambda 8200$. Around $\lambda 4000$ the bands are faint but partially resolved into rotational lines.

Transition. ${}^2\Sigma \rightarrow {}^2\Sigma$, ground state.

ZnCl (*contd.*) **$\lambda\lambda 2993-2903$ SYSTEM**

Occurrence. Observed by Cornell in a high-frequency discharge, and by Walter and Barratt in absorption.

Cornell apparently observed strong sequences (degraded to longer wave-lengths) at $\lambda\lambda 2976.2$ and 2942.6 and a weaker sequence at $\lambda 2910.0$.

The following are the strongest absorption bands (intensities in brackets): $\lambda\lambda 2956$ (8), 2943 (5), 2934 (10), 2923 (5) and 2911 (2).

 $\lambda 2074.4$

A single sequence of bands degraded to the red observed by Cornell in a high-frequency discharge.

ZnF **$\lambda\lambda 2700-2588$ SYSTEM**

Occurrence. In absorption.

Appearance. Degraded to the red.

Reference. G. D. Rochester and E. Olsson, *Z.P.*, 114, 495. (1939).

Heads of the R branches:—

2703.2 , 2676.3 , 2673.1 , 2660.0 , 2634.3 , 2630.0 , 2587.7 .

ZnH

Reference. G. Stenvinkel, *Dissertation*, Stockholm. (1936).

4300 A. SYSTEM ${}^2\Pi \rightarrow {}^2\Sigma$, GROUND STATE

Bands with P and Q heads degraded to the violet, obtained with zinc arc in hydrogen at reduced pressure and in quartz discharge tube containing zinc vapour and hydrogen. See Plate 4.

v', v''	${}^2\Pi_{3/2} \rightarrow {}^2\Sigma$ Origins	Heads (I) Q	P	v', v''	${}^2\Pi_{3/2} \rightarrow {}^2\Sigma$ Origins	Heads (I) Q	P
0, 3	5223.0			0, 3	5131.5		
0, 2	4905.3			0, 2	4824.5		
0, 1	4578.6			0, 1	4523.9		
0, 0	4299.1	4301 (10)	4260 (8)	0, 0	4237.0	4240 (10)	4326 (5)
1, 1	4238.3			1, 1	4178.2		
1, 0	3985.6	3989 (3)		1, 0	3932.2	3935 (3)	
2, 0	3726.0			2, 0	3679.4		

ULTRA-VIOLET SYSTEM ${}^2\Sigma \rightarrow {}^2\Sigma$, GROUND STATE

An extensive system of bands degraded to the red.

v', v''	λ	Origins	v', v''	λ
0, 5	4703.1		4, 0	3219.3
0, 4	4520.0		5, 0	3132.7
0, 3	4310.9		6, 0	3054.1
1, 2	3934.0		7, 0	2981.8
1, 1	3731.7		8, 0	2916.1
2, 0	3418.3		9, 0	2855.7
3, 0	3314.3		10, 0	2800.7

ZnH⁺

Reference. E. Bengtsson and B. Grundström, *Z.P.*, **57**, 1. (1929).

2152 A. SYSTEM, $^1\Sigma \rightarrow ^1\Sigma$

An extensive system of singlet bands degraded to the red. The system is obtained in zinc arc in hydrogen at low pressures. See Plate 5.

v', v''	R Heads
1, 0	2091.7
2, 1	2115.1
0, 0	2151.9
0, 1	2240.2
1, 2	2261.5
0, 2	2332.0
1, 3	2350.7
2, 4	2366.5

ZnI

- References.* A. Terenin, *Z.P.*, **44**, 713. (1927).
 K. Wieland, *Helv. Phys. Acta.*, **2**, 46. (1929).
 E. Oeser, *Z.P.*, **95**, 699. (1935)†.
 P. T. Rao and K. R. Rao, *Indian J. Phys.*, **20**, 49. (1946)†.
 C. Ramasastry, *Indian J. Phys.*, **22**, 119 (1948)† and **23**, 35. (1949).

VISIBLE SYSTEM $\lambda\lambda 6140-3500$

Occurrence. In low-pressure discharge-tubes (Wieland) and in fluorescence of ZnI₂ (Terenin, Oeser).

Appearance. This system, usually referred to as system B, consists of diffuse line-like bands on a continuum with pronounced intensity maximum at 6050 Å. If the spectrum is obtained from ZnI₂ vapour excited in the presence of a large excess of an inert gas, it shows a simplified vibrational structure of bands degraded to the red (Wieland).

Transition. $^2\Sigma \rightarrow ^2\Sigma$, ground state.

SYSTEM $\lambda\lambda 3393-3258$

Appearance. Degraded to shorter wave-lengths.

Transition. Probably $^2\Pi_{1/2} \rightarrow ^2\Sigma$, ground state.

This system is sometimes referred to as system C. Heads of strongest sequences observed by Wieland using a discharge-tube containing ZnI₂ :—

λ	I	v', v''
3367.3	5	0, 2
3342.6	8	0, 1
3318.0	10	0, 0
3291.1	7	1, 0

SYSTEM $\lambda\lambda 3277-3193$

Appearance. Diffuse bands.

Transition. Probably $^2\Pi_{3/2} \rightarrow ^2\Sigma$, ground state.

ZnI (*contd.*)

These bands are considered by Rao and Rao to form with system C the two components of a ${}^2\Pi \rightarrow {}^2\Sigma$ transition. They refer to them as system D. Strongest bands :—

λ	I	v', v''	λ	I	v', v''
3277.7	0	0, 0	3232.5	3	2, 0
3265.7	2		3215.0	3	4, 1
3262.5	3		3212.5	3	3, 0
3257.2	2	3, 2	3196.5	2	5, 1
3254.8	2	1, 0	3193.5	3	4, 0
3235.7	4	3, 1			

SYSTEM $\lambda\lambda 2990-2715$

A large number of bands in this region have been observed by Ramasastry using a high-frequency discharge. He designates them system D_1 . The bands are degraded to the red. Strongest bands :—

$\lambda(I)$; 2989.0 (6), 2983.2 (5), 2971.4 (4), 2952.6 (4), 2946.4 (4), 2872.2 (4), 2823.9 (5), 2817.4 (4), 2815.7 (4), 2764.4 (4).

SYSTEM $\lambda\lambda 2450-2250$

A weak system, degraded to the red, observed in a discharge-tube by Wieland. The system has been studied more extensively by Ramasastry who refers to it as system E. Strongest bands :—

$\lambda(I)$; 2384.5 (4), 2376.8 (4), 2373.1 (4), 2369.4 (4), 2365.2 (4), 2357.8 (4), 2353.5 (5), 2341.9 (5), 2330.1 (3).

ZnS

Reference. P. K. Sen Gupta, *P.R.S.*, 143, 438. (1933-4).

Continuous absorption from 2800 A. to shorter wave-lengths with maximum around 2300 A.

ZrF ?

Reference. M. Afaf, *Thesis Ph.D.*, London. (1949)†.

With an arc containing ZrF_4 Afaf obtained a complex band structure in the region 5100-4900 A. possibly due to ZrF. Strongest heads :—

$\lambda(I)$; 4933.9 (4), 4933.4 (4), 4932.1 (5), 4926.9 (4), 4921.6 (5), 4920.2 (2), 4916.3 (3), 4914.8 (2), 4911.4 (2), 4906.2 (2).

ZrO

Occurrence. Zirconium oxide in arc.

References. F. Lowater, *Proc. Phys. Soc.*, 44, 51. (1932)†.

F. Lowater, *Phil. Trans. Roy. Soc.*, 234A, 355. (1935)†.

The following are the wave-lengths of the strongest heads of the three systems, degraded to the red, obtained by Lowater. The intensities have been reduced to a scale of 10.

ZrO (contd.) **α SYSTEM, BLUE***Transition.* C $^3\Pi \rightarrow$ X $^3\Pi$, ground state.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
4850.1	3	0, 1 R ₁	4521.3	3	3, 2 R ₁
4847.2	3	0, 1 R ₂	4519.3	3	3, 2 R ₂
4827.5	4	0, 1 R ₃	4496.2	4	2, 1 R ₁
4644.7	5	1, 1 R ₃	4493.8	4	2, 1 R ₂
4640.6	10	0, 0 R ₁	4471.5	5	1, 0 R ₁
4637.9	9	0, 0 R ₂	4469.5	4	1, 0 R ₂
4619.8	8	0, 0 R ₃			

 β SYSTEM, YELLOW*Transition.* B \rightarrow X $^3\Pi$, ground state.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
6070.0	3	1, 2 R ₃	5629.0	6	0, 0 R ₂
5809.2	4	3, 3 R ₃	5551.7	5	0, 0 R ₁
5778.5	5	2, 2 R ₃	5545.2	3	4, 3 R ₃
5748.1	8	1, 1 R ₃	5515.3	3	3, 2 R ₃
5724.0	6	0, 0 Q ₃	5491.7	3	5, 4 R ₂
5718.1	10	0, 0 R ₃	5485.7	3	2, 1 R ₃
5658.1	5	1, 1 R ₂	5456.5	4	1, 0 R ₃

 γ SYSTEM, RED*Transition.* A $^3\Sigma \rightarrow$ X $^3\Pi$, ground state.

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
6996.3	3	3, 4 R ₃	6324.3	3	3, 3 R ₁
6959.9	3	2, 3 R ₃	6292.8	7	2, 2 R ₁
6543.0	5	2, 2 R ₃	6260.9	8	1, 1 R ₁
6508.1	9	1, 1 R ₃	6229.4	9	0, 0 R ₁
6473.7	10	0, 0 R ₃	6021.3	3	1, 0 R ₂
6412.3	6	2, 2 R ₂	5977.7	3	3, 2 R ₁
6378.3	8	1, 1 R ₂	5439.4	4	5, 2 R ₁
6344.9	9	0, 0 R ₂			

ULTRA-VIOLET SYSTEMS*References.* G. H. Herbig, *Astrophys. J.*, **109**, 109. (1949)†.M. Afaf, *Nature, Lond.*, **164**, 752. (1949).

Bands degraded to the red have been arranged into three systems by Afaf, whose measurements are given below. Many of these bands were also observed by Lowater, whose list, however, included some Zr lines.

3682 A. System, probably $^1\Sigma \rightarrow ^1\Sigma$

λ	<i>I</i>	v', v''	λ	<i>I</i>	v', v''
3981.4	3	1, 3	3589.9	6	2, 1
3818.3	4	0, 1	3572.0	8	1, 0
3700.1	1	1, 1	3486.7	2	3, 1
3682.1	10	0, 0	3390.0	1	4, 1

ZrO (*contd.*)3507-3472 A. System, perhaps ${}^3\Delta \rightarrow {}^3\Pi$ ground state.

λ	I	v', v''	λ	I	v', v''
3507.6	1	0, 0 Q ₃	3491.8	3	0, 0 R ₂
3506.3	3	0, 0 R ₃	3473.6	1	0, 0 Q ₁
3493.1	1	0, 0 Q ₂	3472.4	3	0, 0 R ₁

3060-2940 A. System, perhaps ${}^3\Pi \rightarrow {}^3\Pi$.

λ	I	v', v''	λ	I	v', v''
3052.4	1	0, 1 R ₃	2967.8	2	0, 0 R ₃
3033.5	1	0, 1 R ₂	2950.0	2	0, 0 R ₂
3023.8	1	0, 1 R ₁	2940.9	2	0, 0 R ₁

INFRA-RED BANDS

References. W. F. Meggers and C. C. Kiess, *Nat. Bur. Stand. J. Res.*, **9**, 325. (1932).
M. Afaf, *Thesis, Ph.D.*, London. (1949)†.

Meggers and Kiess reported a complex group of weak bands, degraded to the red, in the region 9500-9200 A. Afaf found a similar group in the region 8950-8500 A. and suggested that the two groups form the (0, 0) and (1, 0) sequences of a system of bands with five heads.

Strongest heads from these authors :—

$\lambda(I)$; 9370.7 (3), 9360.3 (3), 9356.1 (3), 9329.9 (5), 9315.9 (5), 9299.6 (5), 8744.1 (2), 8734.0 (2), 8721.3 (3), 8709.3 (3), 8695.2 (3).

Afaf also reported a strong band with a conspicuous, though somewhat weak head at $\lambda 8192$ accompanied by a weaker band at $\lambda 8210$ and a number of fairly strong bands without conspicuous heads in the region 7900-7600 A.

PRACTICAL HINTS

THE FOLLOWING SECTION contains a few brief notes on various minor points which arise in the identification of molecular spectra, and which have been found to trouble the inexperienced, but which are not usually dealt with in the general textbooks.

On the Identification of Bands. It should be borne in mind that the most satisfactory comparison of two spectra is made by bringing plates or prints together, side by side. It is preferable that the spectra should be taken with the same instrument in the same state of adjustment, but if this is not possible, enlargements from the plates may be made to the same scale by means of the iron arc comparison spectra. That such direct comparison is not always necessary is of course true; in fact, the object of constructing these tables is largely to make this unnecessary; nevertheless, there will remain cases where one must resort to this method. This is especially true in dealing with sources of very low intensity, such as phosphorescent glows, fluorescence, the night sky, comet tails, etc., where, in order to get a record in a reasonable time, instruments of small dispersion are used with wide slits. In such cases, while the wave-lengths recorded by the observer are not infrequently useless for identification, much may be done with his published photograph. Direct comparison is also useful in dealing with spectra which consist of small regions of continuum, headless bands or other structures lacking outstanding features capable of accurate measurement, and in dealing with spectra which contain several band systems superimposed. Small differences in complicated spectra, otherwise the same, and points of resemblance in spectra mainly different are certainly most readily detected by direct comparison.

Where the dispersion is sufficient to allow of reasonably accurate measurements on well-defined heads, identification by means of wave-lengths becomes practicable. In using these tables the following procedure is suggested as a guide:—

(1) Select two or three of the strongest bands of the spectrum to be identified and compare their wave-lengths with the list of persistent bands. If entries are found in close agreement with these wave-lengths, and if the bands are degraded in the appropriate direction, refer to the detailed list for the corresponding system.

(2) If all of the bands given in the detailed list are found to be present in the spectrum and the details of appearance and occurrence are applicable, the identity may be considered to be established. The approximate agreement of a few of the bands should not be accepted as identification unless the selection can be reasonably explained, *e.g.*, in absorption it may happen that only those bands with $v'' = 0$ are obtained or in fluorescence only those arising from certain values of v' ; a random selection should be rejected. If bands remain unaccounted for in the spectrum they may be an extension of the system, if they are the same type of band, or they may belong to another system of the same molecule. If bands are still outstanding after these possibilities have been examined, select the strongest of them and refer again to the list of persistent bands.

(3) Having identified as many systems as possible by this method, it is usually worth while to refer to the detailed lists for systems of other molecules which may be formed from the elements now known to be present. In this way weak bands which have escaped notice in a crowded spectrum are often detected and accounted for.

(4) Determine the origin of strong atomic lines if any are present. This may provide a clue to an identification, support one already made, or supply the clearest evidence of an unsuspected impurity.

(5) Consider whether the systems obtained are likely to occur in the given source. Such considerations often help to eliminate erroneous identifications due to chance coincidences.

Sources. It is desirable to have some acquaintance with the properties of various sources commonly employed for the production of spectra, both in regard to choosing a source suitable for the production of a given spectrum, and also in regard to assessing the probability of a suspected system appearing in the given source.

The evaluation of the absolute intensities of the band systems of a molecule in different sources requires a knowledge of such quantities as the concentrations of the various atoms and molecules present, the proportion of each in their possible states of excitation and ionisation, with their velocity distributions, as well as the concentration and velocity distribution of electrons, and, in addition, a knowledge of the collision processes which may occur. Such knowledge is not in general available, but fortunately it is possible to make a few generalisations of some value as a result of direct observation, without going into so much detail.

Flames. Many band systems are observed in flames; some by the direct combustion of inflammable substances; others by the introduction of additional substances into a flame already established. The general characteristic of the band systems obtained in this way is that they arise from transitions between a few of the lowest levels of the molecule concerned. The energy of the upper level involved rarely exceeds 5 e-volts, while the lower level is in most cases the ground state. Without exception, flame bands have been found to belong to molecules which are electrically neutral, but very frequently the molecules are not stable in the chemical sense, thus such combinations as CH, NH and OH are of very common occurrence. A few examples will serve to illustrate these points. The 4300 Å. and 3900 Å. bands of CH, the 3064 Å. band of OH and the Swan bands of C₂ appear readily enough in the flames of hydrocarbons, but the Third Positive and the Angstrom bands of CO, which require more than 10 electron volts for their excitation, are absent. Different systems occur most strongly in different parts of the flame; the OH bands are spread through the blue outer cone of a Bunsen flame using coal-gas, but the Swan bands are restricted to the greenish inner cone of the roaring flame, which in fact owes its colour mainly to the presence of these bands. The 3360 Å. band of NH, the 3064 Å. band of OH and the red and violet systems of CN are given by a flame of moist cyanogen. The 3360 Å. band of NH is also obtained strongly from the oxy-ammonia flame, but the systems arising from more excited levels, which are known from other sources, do not appear as well. This is also true of the cyanogen flame. To obtain other systems by the introduction of additional substances, it is necessary that these should be brought to the gaseous state within the flame. Gases and vapours may be mixed directly with the gas being burnt; volatile liquids may be sprayed into the flame and volatile solids introduced on suitable supports. The number of spectra which may be obtained in this way is thus restricted by the necessity of finding suitable volatile substances to add to the flame. This restriction is not so far reaching as it appears at first sight, since the substance whose spectrum is required does not have to be introduced directly, but may be formed as a result of chemical reaction within the flame. Thus in the example mentioned above, although carbon is among the least volatile of all substances, yet the bands of C₂ are readily observed during the combustion of hydrocarbons, even

being observed in a candle flame. Again, in cases where the metallic oxide is refractory, the spectrum of the oxide may be obtained by introducing the metal itself or, more generally, by introducing a volatile halide. Chemical action in the flame also allows the spectra of many metal hydrides to be obtained from flames in cases where the metal does not form a stable compound with hydrogen. Thus the spectra of MgH and CuH may be obtained by putting the finely divided metal into a hydrogen flame and that of NiH by allowing the vapour of nickel carbonyl to mix with the hydrogen. In the examples quoted so far the band systems obtained from flames are readily obtained in other ways, from the electric arc or the discharge tube for the most part, but there are a few systems known which appear readily in the flame yet are not obtained or are only obtained with difficulty in other sources. Such are the CO-flame bands, the ethylene-flame bands and the α -bands of ammonia. It is unlikely that such systems arise from highly excited states of the molecules concerned; it appears more probable that the equilibrium configurations for the excited states differ considerably from those for the normal state. According to the Franck-Condon theory excitation by the absorption of light or by electron impact takes place in such a way that the instantaneous kinetic energy and configuration of the nuclei are unchanged during the change of electronic state; therefore in absorption or in sources where excitation is mainly by electron impact, band systems arising from states in which the configuration of the nuclei differs markedly from that of the normal state may be expected to be weak. In the flame, where excitation occurs mainly as a result of collisions between atoms and molecules, these systems may be relatively strong.

The Arc. In general, arcs develop higher temperatures than flames and therefore are able to volatilise many substances which resist flames. The arc spectra of atoms contain many more lines than the flame spectra, for there is usually sufficient energy available in collision processes in the arc to excite all states up to ionisation, and, in the case of readily ionised elements like calcium, even to excite a few states of the ion. With molecules the behaviour is similar; in the arc spectrum more band systems appear than in the flame spectrum as higher levels are excited. The number of additional systems is not usually great, however, for just as in atomic series the number of lines distinguished is limited by the pressure, so other factors, including pressure, limit the number of band systems. The arc in air has been widely used for the production of the spectra of oxides and halides of the metals; in some cases, such as CuCl and TiO, the bands are more clearly shown in the flame of the arc than in the core. By enclosing the arc it may be run in various gases and at various pressures ranging from a few millimetres of Hg to several atmospheres. The spectra of many of the metallic hydrides have been obtained using arcs in hydrogen at a pressure of a few centimetres of mercury. Reduction of the pressure favours ionisation; thus the spectra of Mg⁺ and MgH⁺ can be obtained easily from an arc between poles of magnesium in an atmosphere of hydrogen by reducing the pressure to a few millimetres of Hg. Increase of pressure up to several atmospheres is sometimes successful in producing band systems not otherwise obtained, such as those of SnH and PbH. This occurs where states of the molecular are subject to predissociation. Band spectra emitted by arcs do not necessarily arise from molecules containing the material of the poles, sometimes only the atmosphere is involved; many arcs produce the OH bands if water vapour is present, and several, notably the Cu arc, produce the NO γ -bands in air. Under reduced pressure such bands as those of PN, NH 3360 A. and the Second Positive system of nitrogen are produced when the appropriate elements are present in the atmosphere. (For high-tension arc see "The Spark.")

Discharge Tubes. Although, as sources of illumination, flames and open arcs have the advantage of simplicity, discharge tubes offer greater scope for the variation of conditions. The discharge tubes formerly used were of low intensity but many of the types now in use compare favourably with the arc in this respect. Moreover, discharge tubes have the additional advantage of steadiness, so that continual readjustment of the image of the source on to the slit is avoided. In what is called the normal discharge seven different regions have been distinguished, viz. : (1) the anode glow, (2) the positive column, (3) the Faraday dark space, (4) the negative glow, (5) the cathode dark space, (6) the cathode glow and (7) the primary dark space. The most luminous parts and therefore those most used in spectroscopy are the positive column and the negative glow.

The Positive Column. With an uncondensed discharge the positive column presents a source which resembles the arc in many ways. The spectra obtained from it are usually those of uncharged atoms and molecules but the number of excited states reached is greater than in the flame or the arc in air. Thus with CO or CO₂ present the Fourth Positive and Angstrom bands of CO appear readily in the positive column although they are not observed in the CO flame and only with difficulty in the arc. Excitation appears to be due mainly to electron impacts, the electrons having a velocity distribution of the Maxwell-Boltzmann type but for a temperature much higher than that of the gas molecules in the tube. The actual distribution depends very much on the nature and pressure of the gas in the tube and on the intensity of the electric field along the column. Both lowering the pressure and increasing the intensity of the field tend to favour higher stages of excitation ; the variation takes place in such a way that the state of excitation appears to depend mainly on the ratio of the field to the pressure, X/p , or perhaps rather more accurately on $X.\lambda$, the product of the field and the mean free path of the electron.

The Negative Glow. In the region of the negative glow there accumulates a considerable positive space-charge. The ions are excited to emission by electrons from the direction of the cathode and as a result the negative glow gives largely the spectra of positively charged ions. A modification of the form of the cathode, known as the hollow cathode, allows fuller advantage to be taken of this peculiarity of the negative glow. The cathode takes the form of a hollow cylinder or a massive block through which a slot has been cut. For a certain range of pressure the negative glow passes into the recess, becoming at the same time more brilliant. For the production of molecular spectra the linear dimensions of the recess are usually greater than for the types of hollow cathode used for the production of fine lines for the study of hyperfine structure.

The Addition of Other Gases. Several molecules are known to emit somewhat different spectra in the presence of different gases. Thus, in the presence of excess of one of the rare gases, CO is found to give the Cameron bands and the Triplet bands. Again, whereas the positive column in pure nitrogen appears of an orange colour, the addition of oxygen causes the colour to change to pink, due to a weakening of the red and yellow bands of the First Positive system of N₂ relative to the blue and violet bands of the Second Positive system. The mechanism in most cases is still somewhat obscure. The following, however, are processes which may be expected to occur. If the excess is an inactive gas, such as one of the rare gases, then excited molecules which ordinarily lose their energy in a collision with their fellows may collide with rare gas molecules without loss of energy. There is then greater probability of the molecule radiating band systems arising from these particular excited states. This is especially

likely to be true for metastable states of the molecule. On the other hand, if there are metastable states of the molecules of the added gas which are excited, these may in a collision hand over their energy to the other molecules, thereby exciting states of these molecules which are not readily excited by electron impact. Also, there is the possibility that the excess of other gas may so modify the velocity distribution of the electrons as to cause a marked change in the relative numbers of molecules excited to different levels.

Controlled Electron Sources. The variation of intensity of the various band systems of a molecule with the velocity of impacting electrons can be studied more accurately in discharge tubes where the velocity can be adjusted as desired. Such tubes usually consist of a heated wire as a source of thermionic electrons, and a grid separated from it by a distance less than the mean free path of an electron at the pressure at which the tube is to be used. By varying the voltage across the grid and filament, the velocity of the electrons can be gradually increased until light is emitted from the gas in the tube. This indicates that molecules of the gas are being raised to an excited state; as the voltage is still further increased, other excited states are reached with the consequent emission of other band systems.

High Frequency Discharges. Two kinds of high-frequency discharge are used fairly extensively in spectroscopic work. They are often spoken of as the ring discharge and the valve oscillator discharge respectively. In the ring discharge a condensed spark is used to set up damped oscillations in a circuit containing suitable inductance and capacity. The inductance consists of a coil of a few turns wound around a spherical or cylindrical vessel containing gas or vapour at low pressure. Under these conditions the gas or vapour may be made to glow brilliantly, the spectra emitted depending on the violence of the discharge, which may be controlled by varying the length of the spark gap. As the violence is increased, the spectrum may be made to change from bands due to molecules to lines due to atoms which have lost several electrons. Decrease of pressure favours greater excitation as with other forms of discharge. In the valve oscillator discharge, a thermionic valve is used to maintain continuous high frequency oscillations in a tuned circuit. A tube containing gas at low pressure may be made to emit radiation by connecting the oscillating circuit to electrodes of the usual type, to external electrodes consisting of foil wrapped around the outside of the tube or to a wire coiled about the tube in the form of an inductance as with the ring discharge. The valve oscillator as generally used with a plate voltage of 1,000–2,000 volts gives spectra which resemble those of the positive column at higher pressures but tend to change to those of the negative glow as the pressure is reduced. High frequency discharges provide a useful means of exciting afterglows and have the advantage that contamination with material from electrodes can be avoided.

Tesla Discharge. The electrodeless discharge from a Tesla coil or "leak tester" generally gives a rather similar spectrum to that of the positive column from a discharge from an induction coil, but it seems to produce less chemical dissociation. It is thus particularly suitable for exciting the electronic spectra of polyatomic molecules such as benzene, glyoxal and formaldehyde; for this purpose a continuous flow of gas through the discharge tube should be maintained.

Active Nitrogen. The ring discharge or condensed discharge through carefully purified nitrogen are both capable of giving rise to a strong orange-coloured afterglow. The spectrum of this afterglow consists of some of the bands of the First Positive system of N_2 . If a small amount of oxygen is mixed with the nitrogen some of the bands of the β -system of NO also appear; in fact, this system is best obtained in this way.

In the positive column of a discharge tube the γ -system is much stronger than the β -system, whereas in the afterglow the reverse is the case. The equilibrium constants for the upper state of the γ -system are much closer to those of the normal state than are those for the upper state of the β -system. Many other band systems can be excited by introducing appropriate gases or vapours into nitrogen thus activated, the excitation often being accompanied by chemical reaction. Thus organic compounds such as CCl_4 and C_2H_2 yield systems of CN, CH, C_2 , and sometimes NH; SiCl_4 yields SiN systems; and, with a trace of oxygen, BCl_3 yields systems of BO. It is usually difficult to remove all trace of oxygen, so that band systems of the oxides often occur quite strongly when other compounds, such as the halides of metals, are added to active nitrogen. A band system produced in active nitrogen often differs considerably in appearance from the same system as observed in the arc or discharge tube; the violet CN bands form a good example. The bands produced in active nitrogen have much shorter branches than in the arc but many more bands of the system are observed; fewer states of rotation are excited, but more of vibration. The energy available for excitation is about $9\frac{1}{2}$ electron volts.

The Spark. The condensed spark discharge is not much used for the production of molecular spectra, since the violence of the discharge is such that many lines of atoms in various stages of ionisation are produced, but few band systems. Sometimes, however, band systems are emitted in an afterglow following the passage of the spark and may be photographed if a synchronised shutter is adjusted to cut off the light of the spark itself from the spectrograph while exposing it to the afterglow. The uncondensed discharge is used in a variety of ways. The discharge from a high tension transformer between metal rods in air is useful for the production of the spectra of some metallic oxides, the bands being obtained with fewer atomic lines and with shorter branches than in the arc; this facilitates vibrational analysis. By enclosing the discharge it may be used to excite the spectra of various gases and vapours, *e.g.*, the Schumann-Runge bands in O_2 . The uncondensed discharge has also been used in conjunction with flames, in some cases to increase the intensity of bands emitted by the flame itself, and in other cases to introduce the vapour of metals of high melting point into the flame for the production of the spectra of their oxides or hydrides. The spectra of the hydrides of nickel, manganese and chromium have been produced in this way by passing the discharge between poles of the appropriate metal in a flame of hydrogen.

Absorption. It is frequently convenient to observe band systems in absorption and this is particularly true where polyatomic molecules are concerned, for these are usually decomposed in emission sources. Observed in absorption a molecular spectrum differs in some respects from one taken in emission. Unless the temperature is unusually high, absorption only occurs for those systems which have the normal state of the molecule as lower level, and only for those bands of these systems which start from the first two or three vibrational levels of the normal state. Thus the absorption spectrum is in general much more simple than the corresponding emission spectrum. If the nuclear configuration for the equilibrium position of the upper state of a system is very different from that for the lower state it may happen that the absorption spectrum shows few if any bands in common with the emission spectrum. In absorption, transitions take place from a few of the lowest vibrational levels of the lower electronic state to high vibrational levels of the upper electronic state, while in emission, transitions take place from a few of the lowest vibrational levels of the upper state to high vibrational levels of the lower state. Since the spacing of the vibrational levels

is different for the two electronic states, it is sometimes difficult to recognise that the bands belong to the same system. This applies particularly to polyatomic molecules.

It is sometimes desired to establish proof of the presence of a molecule, especially if this is a radical not stable chemically, by attempting to observe its spectrum in absorption. Sufficient consideration is not, however, always given to the conditions which must be fulfilled for this observation to be possible. The individual lines of band structure are usually very sharp and will only be observed in absorption if the power of resolution of the spectrograph is comparable with the width of the lines themselves. This usually means that an instrument of high dispersion must be used and the slit kept as narrow as possible. This point is well illustrated by observing how the number of Fraunhofer lines which can be distinguished in the solar spectrum depends on the resolving power of the spectrograph used and on the width of the slit. Since the width of an absorption line depends on the number of absorbing molecules in the line of sight, an increase of the length of absorbing column improves the chance of observing the line, but often, as in dealing with flames and explosions, such increase is limited. Lines crowded together to form heads resemble wide lines and as such may be observed with smaller resolution than is necessary to show the individual lines. It often happens therefore that the head of a band may be observed in absorption but not the open branches which accompany it when it is observed in emission with the same spectrograph.

Collimation. Beginners are sometimes troubled by unduly long exposures, lack of definition, doubling and shading of the lines, these defects arising from poor collimation. Whenever a spectrograph is used, care should be taken to see that it is collimated so that it is used to the best advantage; and this includes the giving of due consideration to the selection and adjustment of optical parts, such as condensing lenses, placed between the source and the slit. Assuming that the optical parts of the spectrograph are without fault, it is essential, to obtain speed and good definition, that the dispersing system, prism or grating, should be uniformly filled with light. At the same time, it is undesirable that additional light should be admitted to the spectrograph through the slit as this extra light, which does not pass through the optical system, is merely scattered within the instrument causing a background of fog on the plate. The ideal is therefore that the light entering the slit should diverge from it in the form of a cone with its axis along the optical axis of the collimator and its base just filling the optical system. If the source is sufficiently extended, it may be brought near enough to the slit for this condition to be fulfilled; if it is not, a condensing lens must be used. In either case, the first adjustment is to arrange the source so that it is on the axis of the collimator. A simple procedure for making this adjustment is as follows: The slit of the spectrograph is opened to about 1 mm. and the source moved (the standard iron arc is convenient for this purpose) both laterally and vertically until the narrow pencil of light entering the slit falls on the centre of the prism or grating of the spectrograph. If a condensing lens is to be used it is next put in place so as to focus an image of the source on the slit. It is an advantage to use the enlarged rather than the diminished image on the slit, provided care is taken to ensure that the full aperture of the spectrograph is used. Use of the diminished image does not give an increase of speed proportional to the brightness of the image, since the light is spread over a cone of larger solid angle, thus more than filling the optical system and flooding the spectrograph with light. The diminished image also has the additional disadvantage of giving a very narrow and uneven spectrum. When the source and lens have been set in position the adjustment should be checked by placing the eye in the plane of the

spectrum and observing whether the optical system is completely and uniformly filled with light. When collimating it is often useful to remember that light travelling in the opposite direction takes the same path through an optical system. Thus with large concave gratings, where the grating and source rooms are separate, it is convenient to place a small strip of white paper in front of the grating, illuminate it so that it may be seen through the slit from the source room, and then to place the arc (with current off) in line with the paper and the slit. The lens may then be arranged to focus the image of the arc on the slit. Again, if a source is difficult to move when running it may be set in position, once the lens has been fixed, by illuminating the slit, finding the real image of the slit, and then adjusting the source to coincide with this image. In the majority of experiments a condensing lens is used. Once the lens has been adjusted to be on the axis of the instrument it may be kept there and the source changed as required, the source automatically coming on to the axis when its image is focused on the slit. If the work is sufficiently routine, it may be worth while to arrange an optical bench in conjunction with the spectrograph. Concave mirrors may also be used to focus the source on to the slit and have the advantage that the image is achromatic. Mirrors, however, are otherwise inconvenient and lenses are generally preferred. It must be remembered, when using a lens, that the different wave-lengths come to a focus at different distances from the lens. With large instruments, when only a small region of the spectrum is being photographed at a time, this is not serious if care is taken to focus for the wave-length region required, but with small instruments covering a large range, such as the usual quartz spectrographs, it may lead to great variations of intensity. If a particular region is required the lens may be adjusted to bring this to a focus, but if the whole range is required, as in exploratory work, it is usually of advantage to focus the farthest ultra-violet image on the slit. This may be done by using a fluorescent screen in front of the slit and a source, such as the copper arc, which is rich in lines about 2100 Å. to adjust the lens. In this way a very uniform intensity may be obtained from the visible to the far ultra-violet.

Comparison Spectra. To obtain the wave-lengths of features of a spectrum, a comparison spectrum is photographed alongside. The comparison most generally used is the iron arc. The spectrum of the iron arc contains a very large number of sharp strong lines distributed fairly evenly from about 2330 Å. to the infra-red region; there are one or two gaps and the orange region is somewhat confused by bands of FeO, but on the whole it is good throughout the visible and near ultra-violet regions. The lines have been investigated by the International Astronomical Union and accurate standard values of their wave-lengths set up. To obtain the highest accuracy the form of arc lamp used to produce the spectrum has been standardised following the recommendations of Pfund. The electrodes are vertical; the anode below, consisting of a bead of iron oxide supported on a massive rod of iron, and the cathode above, consisting of a rod of iron 6–7 mm. in diameter, having a massive cooling cylinder of copper or iron close to the end of the rod. The arc is operated on a 110–250 volts supply with a current of 5 amperes or less. For accurate measurements the arc should be 12–15 mm. long and light should be taken only from the central zone at right angles to the axis of the arc not exceeding 1.5 mm. in width.

For the region 2000–2300 Å. the copper arc is employed. Since the spectrum of the copper arc is relatively simple it is sometimes used as a general comparison spectrum for work with small dispersion. The practice is not, however, much to be recommended as the appearance of the spectrum is rather variable, there are few lines at the red end of the spectrum, and bands of NO often confuse the ultra-violet region.

Mercury shows far too few lines to be of much use as a comparison spectrum, but the frequent employment of the mercury arc as a source for fluorescence and photochemistry has led to its adoption for this purpose. The principal features of the spectrum are of course very easily recognised.

For the yellow and red regions a neon spectrum has been recommended. A neon discharge tube is a very convenient source but unfortunately the lines are rather far apart for use with high dispersion and the useful range is very limited. For the photographic infra-red, a barium arc (Ba salt on carbon poles) is a useful wave-length guide for work with small dispersion.

Reproductions of the spectra of iron, copper, mercury and neon are shown in Plates 11 and 12.

Measurement. If a spectrum is to be measured the comparison spectrum should be photographed alongside, so that there is a slight overlap. In doing this the adjustments of the spectrograph, the plate holder and the dark slide should not be disturbed between the two exposures; the spectra are brought into the desired positions by use of a Hartmann diaphragm in front of the slit for a prism instrument, and by use of a Rowland shutter in front of the plate for a grating instrument.

To obtain the wave-lengths, a travelling microscope with a screw accurate to 0.001 mm. is used to measure the positions of the bands or lines under investigation and a sufficient number of lines of the comparison spectrum. Care should be taken always to approach the line or band from the same direction, and after completing the measurements in one range the plate should be reversed, end to end, and a second run made. Reversal of the plate is very important when the lines measured differ much in definition or intensity, as individual observers show, as a rule, a tendency to set regularly off centre by an amount depending on the character of the line. Reduction to the mean setting is greatly facilitated if the scales of the microscope are graduated in both directions, as subtraction is thereby eliminated and there is no difficulty in identifying corresponding readings.

The microscope scale readings are converted to wave-lengths by use of a suitable interpolation formula. In the measurement of grating plates a linear formula,

$$\lambda = \lambda_0 + S.D$$

is used, where λ_0 is a constant depending on the zero of the scale, S is the scale reading and D is the dispersion of the spectrograph. Two carefully chosen lines of the comparison spectrum, one at either end of the range, are used to determine the constants of the formula; the remaining comparison lines are used to construct a correction curve for deviations from this approximate formula. For prism spectrograms a three-constant formula,

$$\lambda = \lambda_0 + C/(S + S_0)$$

is generally used, where λ_0 is a constant depending on the material of the prism, C is a constant depending on the dimensions of the instrument, S is the scale reading and S_0 is a constant depending on the position of the scale zero. As before, the constants of the formula are obtained from carefully chosen standard lines, this time using one, in the middle of the range as well as one at either end, and a correction curve is constructed from the remainder. In the measurement of short ranges the calculation is simplified by assuming an approximate round number for λ_0 and using two standard lines to give the other constants. With this procedure a correction curve is essential, and the corrections are larger than would be the case with the three constant formula,

but there is the advantage that the curve does not contain a point of inflection. If the standard lines are converted to wave-numbers a linear formula,

$$\nu = \nu_0 + S.K$$

for wave-numbers may be used. This is much easier for use with a calculating machine, but the formula is still less accurate than the last and places a correspondingly greater burden on the correction curve.

In measuring band heads the crosswires of the microscope should not be set on the extreme edge of the band, but an attempt should be made to allow for the finite width of a line by setting half a line width within the head. Unless this is done the value obtained for the wave-length of the head may vary considerably from spectrograph to spectrograph, and if a wide slit is used may lead to discrepancies of several angstroms.

In measuring very faint lines it is generally found to be of some slight advantage to use blue light to illuminate the plate; faint lines appear a little more distinctly with the shorter wave-length illumination, possibly on account of greater scattering by the grains of the plate.

Spurious Bands. When using a quartz spectrograph care should be taken to avoid the light from the source becoming polarised before reaching the spectrograph. With polarised light, interference between the ordinary and extraordinary rays may introduce into a continuum a banded structure not unlike a diffuse band spectrum. The bands are usually too regular to be mistaken for a real molecular spectrum when strong and isolated, but if superimposed on a band system may cause errors in measurements of wave-length and intensity. The light may be polarised if reflectors are used to bring the image on the slit. Light from a discharge tube is often slightly polarised, probably by reflections within the tube.

If plates are not rocked or brushed during development broad lines or bands may become more strongly developed at the edges than in the centre, giving a spurious resolution into two.

With long exposures in a well-lit room it is possible for sufficient diffuse daylight to enter the slit to record the solar spectrum with the stronger Fraunhofer lines, particularly the H and K lines of Ca^+ . If their origin is not recognised, these may be attributed to absorption bands from the source in use.

DESCRIPTION OF PLATES

Below are given brief indications of the source used and of the type of spectrograph employed, viz., concave *grating*, *glass* prismatic instrument, or *E. 1* (large Littrow type) *E. 2* (medium) or *E. 3* (small) quartz spectrograph. Where the plate has been taken by other than one of the present authors this is indicated by the name in brackets.

Plates 1 to 10 all show positive enlargements, while the comparison spectra shown in Plates 11 and 12 are reproductions of negatives.

- Plate 1. CaF. Calcium fluoride in carbon arc ; glass.
CaO. Calcium carbonate in carbon arc ; glass.
AlO. High tension arc between Al electrodes ; grating. (W. Jevons.)
AlCl. Discharge tube ; E. 1. (B. N. Bhaduri.)
SiO. Heated silica discharge tube ; grating. (R. F. Barrow.)
- Plate 2. Angstrom, Herzberg and Triplet Systems of CO. Positive column of discharge through CO₂ ; glass. (A. Fowler.)
Third positive and 5B bands of CO. Positive column of discharge through CO₂ ; E. 2. (A. Fowler.)
Fourth positive bands of CO. Positive column of discharge through CO₂ ; E. 2. (A. Fowler.)
CO⁺, first negative. Negative glow of discharge through CO₂ ; E. 2. (A. Fowler.)
CO₂ (or CO₂⁺). Negative glow of discharge through flowing CO₂ ; E. 2. (A. Fowler.)
- Plate 3. N₂, first positive. Positive column of discharge through N₂ ; glass.
N₂, second positive. Positive column of discharge through N₂ ; E. 1. (R. C. Pankhurst.)
N₂⁺. Negative glow of discharge through N₂ ; E. 2.
NO β. Active nitrogen ; E. 2. (A. Fowler.)
NO γ. Positive column of discharge through air ; E. 2.
- Plate 4. H₂, blue region. Discharge through H₂ ; glass.
H₂, red region. Discharge through H₂ ; glass.
OH. Bunsen flame ; E. 2.
CH. Discharge (? acetylene) (?).
NH. Discharge through flowing NH₃ ; E. 2. (R. W. Lunt.)
CuH. High-tension arc in hydrogen flame ; E. 2.
ZnH. Zn in discharge through H₂ ; E. 2.
CdH. Hollow cathode ; E. 2. (E. W. Foster and A. G. G.)
- Plate 5. NaH. Discharge through H₂ and Na vapour ; E. 2. (R. C. Pankhurst.)
MgH. Arc with Mg electrodes in H₂ ; glass. (A. Fowler.)
MgH⁺. Arc with Mg electrodes in H₂ ; E. 1.
ZnH⁺. Arc with Zn electrodes in H₂ ; E. 1.
PH. Discharge through H₂ and P₂ vapour ; E. 1.
MnH violet and blue systems. High tension arc between Mn electrodes in H₂ flame ; glass.
MnH green system. As above.
NiH. High-tension arc between Ni electrodes in H₂ flame ; glass.
- Plate 6. Condensed discharge through N₂ ; E. 2.
NS. Uncondensed discharge through N₂ and sulphur vapour ; E. 1. (C. J. Bakker.)
NS. As above continued.
PO. P₂O₅ in arc in air between Cu poles ; E. 1.
P₂. Uncondensed discharge through P₂ + H₂ ; E. 2.
- Plate 7. O₂. Schumann-Runge. High-tension arc in O₂ at atmospheric pressure ; E. 1. (M. W. Feast.)
O₂. Schumann-Runge continued.
O₂⁺. Second negative. High-frequency discharge through O₂ ; E. 1. (M. W. Feast.)
O₂⁺. Second negative continued.
O₂⁺. Second negative continued, and first negative.

DESCRIPTION OF PLATES (*continued*)

- Plate 8. O₂ Schumann-Runge absorption. 3 m. vacuum grating. (H. P. Knauss and S. S. Ballard, *Phys. Rev.*, **48**, 796 (1935).)
 O₂ Schumann-Runge. Atmospheric absorption; E. 3.
 O₄. Absorption by oxygen at 50 atm. pressure; E. 2. (Enlarged from a print kindly supplied by K. Wieland.)
 NO₂. Absorption by heated NO₂; glass. (L. Harris and R. W. B. Pearse.)
 SiF. Discharge through SiF₄; glass.
 TiO. TiO₂ in arc with Fe electrodes; glass. (A. Fowler.)
 CO⁺. Discharge at very low pressure; glass. (A. Fowler.)
 CH₂O. Tesla discharge through flowing formaldehyde vapour; E. 2. (J. C. D. Brand.)
- Plate 9. Bunsen flame. Inner cone; E. 2.
 Ethylene flame. Inner cone; E. 2.
 CO flame. E. 2; on process plate.
 C₂, Swan. Discharge (? acetylene); glass (?).
 CN, violet system; glass.
 CN, red system. CCl₄ in active nitrogen; glass. (A. Fowler.)
 CS and S₂. Sulphur in carbon arc; E. 3. (L. C. Martin.)
 FeO. Iron carbonyl in flame; glass.
- Plate 10. CuCl. Cuprous chloride in carbon arc; glass.
 CuO. Arc in air between Cu electrodes; grating.
 BO. Boric acid in carbon arc; glass.
 SO and SO₂. Discharge through flowing SO₂; E. 3. (B. N. Bhaduri.)
 SO₂ absorption. Hydrogen continuum; E. 2.
 C₆H₆. Absorption by vapour; hydrogen continuum; E. 2.
 CH₂O. Absorption by formaldehyde vapour; hydrogen continuum; E. 2. (G. H. Young.)
 I₂. Absorption by iodine vapour; incandescent filament; glass.
- Plate 11. Comparison spectra. Iron, copper and quartz mercury arcs, and neon discharge tube.
- Plate 12. Comparison spectra. Iron arc.

Cr		3734.87	7a	Hg		Li	
5208.43	6	3719.94	7a	5790.66	5	6707.86	10a
5206.04	6	3581.20	7	5769.60	5	6103.64	5
5204.54	6	3570.10	7	5460.73	6	4602.99	4
4289.72	9a	3475.46	7a	4358.34	6	3232.61	3a
4274.80	9a	3465.86	7a	4046.56	6		
4254.34	10a	3020.65	7a	3650.15	6	Lu	
3605.35	9	2522.86	7a	2536.52	9a	4518.54	5
3593.48	9	2488.15	7a	1849.6	10a	2911.39	2
3578.69	10	2483.28	8a			2894.84	1
				Ho			
Cs				3891.02	5	Mg	
8943.50	10a	Ga		3748.19	1	5183.62	8
8521.15	10a	4172.05	10a			5172.68	7
4593.18	7a	4033.01	10a	I		5167.33	6
4555.36	8a			5464.61	3	3838.26	7
				5161.19	5	3832.31	6
Cu		Gd		3288.3	—	3096.92	8
5220.06	4	3768.40	2	2062.38	—	2852.13	10a
5218.20	5	3646.19	10				
5153.26	4			In		Mg⁺	
5105.55	4			4511.31	10a	2802.71	8
3273.96	9a	Ge		4101.76	8	2795.54	8
3247.55	10a	4226.61	7	3256.08	8		
		3269.49	7	3039.36	7	Mn	
		3039.08	8			6021.79	3
Dy		2754.59	8	Ir		6016.64	3
4211.72	4	2709.61	8	3513.67	5	6013.50	3
4167.97	1	2651.18	8	3220.79	5	4034.49	10a
4077.98	3			3133.34	5	4033.07	10a
4046.00	3					4030.76	10a
4000.50	8	H		K		2798.27	6
		6562.79	8	7698.98	9a		
Er		4861.33	6	7664.91	10a	Mo	
3906.34	5	4340.47	4	4047.22	4a	3902.96	7a
3692.65	4			4044.16	5a	3864.12	8a
3499.12	3	He				3798.26	8a
		5875.62	5	Kr		3193.98	6a
Eu		4685.75	2	5870.92	5	3170.34	6a
4205.03	5	3888.65	5	5570.29	5	3132.60	6a
4129.73	3						
				La		N	
F		Hf		6249.93	4	4935.03	—
6902.46	4	4093.17	2	5930.65	3	4447.0	—
6856.01	5	3134.72	8	4429.90	5	4109.94	5
		3072.88	8	4333.80	5	4099.94	2
Fe		2940.77	6	4123.23	6		
4957.61	5	2916.48	5	4086.71	6	N⁺	
4920.52	5	2904.41	3	3949.10	8	5679.5	5
4891.50	4	2898.25	5	3337.49	7	5666.6	5

APPENDIX

267

Na		Pd	2311.50	6a	Ta		
5895.93	9a	3634.68	2	2175.89	8a	6485.36	1
5889.96	10a	3609.55	2	2068.38	8a	3318.85	5
3302.94	4a	3516.95	4			3311.14	5
3302.34	4a	3421.23	6	Sc		2714.68	8
		3404.59	8	4023.72	8		
Nd				4020.42	5	Tb	
4303.61	5	Pr		3911.81	8	3874.19	5
4177.34	1	4225.34	1	3907.48	5	3848.76	2
3951.15	2	4189.52	2			3561.75	5
		4179.43	5	Se		3509.18	5
Ne		4062.83	3	4742.25	3		
6402.25	8			4739.03	4	Te	
5852.49	8	Pt		4730.78	5	2769.65	4
5400.56	8	3064.71	8	2062.79	4a	2385.78	5
		2659.44	8	2039.85	5a	2383.27	5
						2142.75	4a
Ni		Ra		Si		Th	
3524.54	7a	4825.94		3905.52	1	4019.14	
3515.06	4a			2881.59	8	3601.05	
3446.26	6a	Rb		2528.52	4	3538.75	
3414.77	8a	7947.63	10a	2524.12	4		
		7800.23	10a	2516.12	5	Ti	
O		6298.6	5	2506.90	4	4999.51	2
7771.95	5	4215.58	8a			4981.73	3
6158.21	3	4201.81	8a	Sm		4536.05	4
5330.65	2			4424.35	5	to	
4368.30	2	Rh		4390.87	2	4533.25	
3947.29	2	4374.82	4			3998.64	6
		3692.35	4	Sn		3371.46	6
Os		3434.90	8	5731.70	1	3341.87	8
4420.46	3			3262.33	9		
4260.85	3	Ru		3175.05	10a	Ti⁺	
3267.94	6	3728.02	4	3034.12	8a	3372.80	6
3058.66	6	3726.93	4	2863.32	10a	3361.22	6
2909.08	8	3498.95	8	2839.99	10a	3349.41	6
2488.55	6	3436.74	4	2706.50	8a	3349.04	5
						Tl	
P		S		Sr		5350.47	10
2554.93	5	4696.25	3	4962.26	3	3775.73	9a
2553.28	8	4695.45	4	4872.49	2	3519.24	7
2535.65	8	4694.13	5	4832.08	5	2918.32	2
2534.01	6			4607.33	10a	2767.87	2a
		Sb				Tu	
Pb		3267.48	4	Sr⁺		3761.91	4
4057.83	10	3232.52	2	4215.52	6	3761.34	5
3683.47	8	2877.92	8	4077.71	10	3462.21	4
3639.58	6	2598.08	8				
2833.07	5a	2528.53	8				
2170.00	—						

THE IDENTIFICATION OF MOLECULAR SPECTRA

U		4294.62	5	3774.33	6	2138.61	5a
5527.84		4008.76	8	3710.30	6		
4241.68		3617.52	3	3242.28	6	Zr	
3672.58						4710.07	1
		Xe		Yb		4687.80	2
V		4671.22	5	3988.01	5	3601.19	5
4460.31	5	4624.27	2	3694.20	3	3547.68	3
4408.52	5	4500.98	1	3289.73	3	3519.61	2
to						3481.15	1
4379.24	8			Zn			
4128.07	8	Y		6362.35	6	Zr⁺	
3185.41	8	4674.85	4	4810.53	10	3572.47	1
3183.99	8	4643.69	2	4722.16	10	3496.21	2
		4374.95	4	4680.14	9	3438.23	3
W		4142.87	6	3344.91	9	3391.98	5
4302.11	6	4102.38	8				

For the most complete and recent work on line spectra, the reader is referred to "Massachusetts Institute of Technology Wave-length Tables," edited by G. R. Harrison (John Wiley and Sons, New York; Chapman and Hall, London; (1939)).

Conversion of Wave-lengths on Rowland's Scale to International Angstroms

Range in A.	Correction (subtract)	Range in A.	Correction (subtract)
2950-3125	0.12	5400-5500	0.21
3125-3250	0.13	5500-6050	0.22
3250-3450	0.14	6050-6500	0.21
3450-4150	0.15	6500-6570	0.22
4150-4350	0.16	6570-6750	0.23
4350-4550	0.17	6750-6850	0.24
4550-5125	0.18	6850-7000	0.25
5125-5300	0.17	7000-7200	0.26
5300-5325	0.18	7200-7400	0.27
5325-5375	0.19	7400-7700	0.28
5375-5400	0.20		

Conversion of Wave-lengths in Air to Wave-lengths in Vacuo

λ_{air}	add	λ_{air}	add	λ_{air}	add	λ_{air}	add
15,000	4.10	7800	2.14	5800	1.60	3800	1.07
14,000	3.83	7600	2.09	5600	1.55	3600	1.02
13,000	3.55	7400	2.04	5400	1.50	3400	0.97
12,000	3.28	7200	1.98	5200	1.44	3200	0.92
11,000	3.01	7000	1.93	5000	1.39	3000	0.87
10,000	2.74	6800	1.87	4800	1.34	2800	0.82
9500	2.60	6600	1.82	4600	1.28	2600	0.78
9000	2.46	6400	1.77	4400	1.23	2400	0.73
8500	2.33	6200	1.71	4200	1.18	2200	0.69
8000	2.20	6000	1.66	4000	1.13	2000	0.65

Physical Constants, etc.

c	velocity of light, 2.9977×10^{10} cm./sec.
e	electronic charge, 4.802×10^{-10} E.S.U.
h	Planck's constant, 6.624×10^{-27} erg. sec.
k	Boltzmann factor, 1.381×10^{-16} erg./deg.
N	Avogadro's number, 6.023×10^{23} molecules/mole.
n	Loschmidt's number, 2.687×10^{19} molecules/c.c. at S.T.P.
m	mass of electron, 9.107×10^{-28} gm.
m_H	mass of hydrogen atom, 1.673×10^{-24} gm.
R_H	Rydberg constant for hydrogen, 109677.7 cm. ⁻¹
R_∞	Rydberg constant, infinite mass, 109737.1 cm. ⁻¹
1 A. (angstrom)	= 10^{-8} cm.
1 μ (micron)	= 10^{-4} cm.
1 gm. calorie	= 4.185×10^7 ergs.
1 electron-volt	= 1.602×10^{-12} ergs.
1 electron-volt	= 8067.5 cm. ⁻¹ (wave-numbers) = 23,053 gm. cal./mole.
1 cm. ⁻¹	= 2.86 gm. cal./mole.

AUTHOR INDEX

- A**ARS, 128
 Afaf, 250, 251, 252
 Ainslie, 153, 208
 Almkvist, 238
 Almy, 49, 51, 52, 57, 58, 70, 122, 154
 Appleyard, 171
 Arvin, 189
 Ashley, 200
 Asundi, 75, 76, 78, 81, 87, 91, 93, 95, 219, 220, 222
 Austin, 81
- B**ABCOCK, 195
 Bacher, 164, 165, 166
 Badami, 179
 Badger, 90, 136, 140, 149, 180
 Bair, 182, 214
 Bakker, 186, 263
 Baldet, 97, 98
 Ball, 202
 Ballard, 194, 264
 Barker, 98
 Barratt, 61, 65, 102, 107, 112, 121, 122, 141, 148, 154, 155, 157, 162, 187-190, 209-211, 233, 236, 247
 Barrow, 43, 45, 62, 121, 133-135, 163, 207, 208, 210, 220, 225, 226, 230-232, 238, 263
 Barton, 180
 Barwald, 100
 Bashford, 133, 134, 221, 227
 Bates, 53
 Bauer, 140
 Baumann, 138, 195
 Bawn, 100
 Beer, 92
 Beiler, 154
 Bell, 68-70
 Benedict, 185
 Bengtsson, 44, 48, 54, 68, 69, 114, 249
 Bernard, 170
 Bhaduri, 47, 214, 263, 264
 Binder, 136
 Birge, 171
 Birkenbeil, 168
- Biskamp, 96
 Black, 81
 Bloomenthal, 206
 Bonner, 185
 Bowen, 86
 Bozoky, 197
 Brand, 264
 Brandt, 200
 Brice, 43, 45
 Briscoe, 133, 134
 Brodersen, 74, 109, 110
 Brons, 97, 169, 176
 Brown, 73, 149
 Bueso-Sanllehi, 100
 Bulthuis, 97
 Butkow, 242, 245
- C**AMERON, 94, 117, 225
 Caunt, 121, 210
 Chakraborti, 154
 Chow, 214
 Christy, 153, 206, 211, 242
 Clements, 213
 Coleman, 74, 75, 150
 Connelly, 53, 230
 Cordes, 149
 Cornell, 112, 143, 247
 Coster, 97, 169, 176
 Cotton, 95
 Coulson, 242, 243
 Coy, 216
 Cram, 111
 Crane, 153
 Crawford, 62, 101, 157, 163
 Curry, 201, 202
 Curtis, 140, 149, 150, 211
- D**ARBYSHIRE, 73, 150
 Datta, 62, 104, 159, 235
 Dawsey, 140
 Debye, 185
 de Gramont, 224
 de Laszlo, 223
 Delsemme, 131
 Désirant, 102, 239

- de Watteville, 224
 Dhavale, 190
 Dieke, 77, 92, 194, 195
 Douglas, 55, 58, 79
 Downie, 220
 Duchesne, 214, 220, 240
 Duffendack, 91, 92, 98
 Duffieux, 184
 Dull, 56
 Duncan, 179
 Dutta, 185
- EISLER**, 230
 Elliott, 117, 149, 177
 Ellsworth, 197
 Emeléus, 84
 Eriksson, 51
 Estey, 91
 Evans, 149
 Eyster, 222
- FEAST**, 89, 194, 197, 199, 209, 263
 Ferguson, 54, 216, 227
 Ferrieres, 179
 Finkelberg, 195
 Foster, 245, 263
 Fowler, A., 47, 75, 76, 87, 99, 100, 140, 168, 170, 177, 179, 186, 198, 211, 242, 263, 264
 Fowler, C. A., 62, 67, 104, 113, 159, 160, 227, 235
 Fox, G. W., 91
 Fox, J. G., 75-77, 92, 98
 Franck, 43, 45
 Franz, 84, 143
 Fredrickson, 65, 66, 153, 187, 236
 Frerichs, 197
 Freudenburg, 138
 Füchtbauer, 194
 Funke, 65, 177
- G ALE**, 128, 135
 Gaydon, 74, 75, 86, 87, 99, 118, 120, 123, 130, 139, 150, 165, 168, 169, 172, 174, 175, 179, 180, 182, 183, 191-193, 211, 212, 215, 245
 Genard, 215
 Gerö, 93-95, 170
 Geuter, 202
- Ghosh, C., 73, 120
 Ghosh, P. N., 202
 Gibbs, 134
 Gibson, 51, 150
 Goodeve, 119
 Gradstein, 84
 Grebe, 199
 Gregory, 177
 Grenat, 79
 Grillet, 184
 Grinfeld, 160
 Grundström, 65, 106, 126, 152, 244, 249
 Guernsey, 132, 152
 Guillery, 183
 Guntsch, 128, 160, 161, 162
 Gupta, A. K. Sen., 73, 148, 166, 216
 Gupta, P. K. Sen., 116, 250
- HAMADA**, 159, 174, 247
 Hansche, 94
 Harris, L., 185, 264
 Harris, W. T., 161
 Harrison, 268
 Harvey, 62, 68-70, 104, 155, 235
 Hause, 154
 Headrick, 91
 Healey, 100
 Hedfeld, 61, 81, 102, 103, 107, 233, 234
 Heimer, A., 72, 120, 125, 130, 165, 191
 Heimer, T., 54, 79, 125
 Hellermann, 183
 Hemptinne, 86
 Henri, 81, 84, 185, 213
 Herbig, 251
 Herczog, 115
 Herman, L., 93
 Herman, R., 80, 93, 168, 171, 172, 174
 Herman, R. C., 195
 Hertenstein, 127
 Herzberg, G., 55, 56, 58, 75-77, 79, 80, 84, 88, 91, 94, 100, 168, 176, 195, 200, 201, 202
 Herzberg, L., 68, 100, 201, 202
 Hirschlaff, 149
 Hochberg, 131, 150, 151
 Hogan, 66
 Holm, 194
 Holst, J. W., 48
 Holst, W., 47-49

Holtz, 199
 Hopfield, H. S., 195
 Hopfield, J. J., 171, 195, 197
 Hori, 79, 145, 154, 188
 Hornbeck, 193, 195
 Horsfall, 57, 58
 Howell, 47, 71, 112, 115, 142-144, 146,
 206, 207, 242, 243, 247
 Hudes, 216
 Hulthén, 48, 51, 91, 106, 145
 Humphreys, 67, 68
 Hund, 42, 43
 Hushley, 56

JACK, 199

Jackson, 223
 Jakowlewa, 198, 200
 Janin, 172, 199
 Jan-Khan, 220
 Jasse, 91
 Jausseran, 184
 Jenkins, F. A., 44, 53, 59, 62, 67, 87, 89,
 155, 160, 180, 223, 228
 Jenkins, H. G., 180, 222
 Jennergren, 47
 Jevons, 51, 60, 67, 75, 89, 101, 133-135,
 155, 160, 193, 221, 223-225, 227, 263
 Johnson, L. W., 246
 Johnson, R. C., 57, 75-77, 91, 93, 96-98,
 104, 180, 197, 199, 222, 235, 246
 Johnston, 119
 Jorgensen, 157

KALLMANN, 143

Kaplan, 96, 170, 174
 Karim, 78
 Kiess, 238, 252
 Kimball, 53,
 Kimura, 149, 187
 King, A. S., 109, 141
 King, G. W., 185
 Kinzer, 51, 52
 Kistiakowsky, 80
 Kitagawa, 73, 139
 Klemenc, 75
 Knauss, 56, 95, 183, 194, 264
 Koana, 199
 Kondratjew, 84, 198
 Koontz, 64, 176
 Krishnamurti, 146

Ku, 119
 Kulp, 137, 157, 187, 188, 190
 Kuhn, 43, 45, 73
 Kusch, 121

LAGERQVIST, 68, 69, 133, 162, 163

Laird, 117
 Lal, 197
 Laubengayer, 134
 Lee, 135
 Lejeune, 110, 127
 Levanas, 140
 Lewis, 212
 Liebermann, 102
 Liefson, 139, 193
 Lindau, 169
 Lindholm, 136
 Liu, 90, 137
 Lochte-Holtgreven, 77, 100, 194
 Lohmeyer, 142, 143, 146
 Long, 140
 Loomis, 46, 121, 127, 148, 153, 187, 189,
 200, 230
 Lorinczi, 93
 Lotmar, 214
 Lowater, 241, 242, 250
 Lunt, 178, 263

MACFARLANE, 51

McKellar, 59, 157
 McLennan, 153, 196, 209
 McVicker, 82
 Mahanti, 66, 110, 127, 162, 163, 237, 245
 Mahla, 238
 Malet, 120, 130, 192
 Marsh, 82
 Martin, E. V., 213
 Martin, L. C., 101, 264
 Matuyama, 141, 209
 Mauchly, 92
 Mecke, 81, 138, 148, 169, 180, 195
 Meggers, 108, 109, 141, 155, 158, 217, 246,
 252
 Melvin, 137, 198
 Merton, 93, 97, 176
 Mesnage, 44, 119, 120, 129, 163, 164, 190, 191
 Metropolis, 45, 46
 Miescher, 50, 55, 56, 129, 131, 132, 150-
 152, 243

Migeotte, 184, 239
 Minne, 239
 Miyanis(h)i, 149, 219
 Monfils, 80
 Monfort, 218
 Monk, 128, 135
 More, 119, 191, 240
 Moreczewska, 218
 Morgan, 71-73, 159, 162, 203, 204
 Mrozowska, 99, 141
 Mukkerji, 216
 Mulcahy, 43, 45
 Müller, 129, 163, 164, 240
 Mulliken, 59, 60, 77, 126, 127, 146, 180,
 197, 223

NAKAMURA, 70, 157, 178, 215
 Naudé, 211, 215
 Nevin, 62, 165, 197, 218
 Newburgh, 203-205
 Newitt, 137
 Nilsson, 48
 Norling, 136
 Nusbaum, 153

OGAWA, 184
 Oeser, 112, 115, 247, 249
 Okubo, 141
 Olmstead, 65, 103, 108, 233, 236
 Ossenbruggen, 195
 Ota, 74, 117
 Outridge, 137

PADHYE, 81
 Pankhurst, 169, 188, 224, 225, 263
 Pannetier, 118
 Parker, A. E., 61, 103, 176, 234
 Parker, A. H., 240
 Parti, 219
 Patkowski, 150
 Pearse, 84, 120, 161, 162, 165, 178, 185,
 191, 201, 211
 Petrikaln, 131, 150, 151, 202
 Piaw, 219, 220, 239, 240
 Piccardi, 132, 166, 190, 209, 226
 Pilley, 176
 Plantinga, 133, 209
 Poetker, 168
 Pomeroy, 151

Price, 213
 Prileshajewa, 146
 Pringsheim, 149
 Purkis, 86

RAFFETY, 79
 Ramanadham, 202
 Ramasastry, 112, 115, 146, 202, 249
 Ramsperger, 150
 Rao, B. N., 115, 146
 Rao, G. V. S. R., 202
 Rao, K. R., 45, 115, 146, 245, 249
 Rao, N. A. N., 115, 146
 Rao, P. T., 73, 243, 245, 249
 Rao, V. R., 111, 146
 Rassweiler, 122, 206
 Rathenau, 139
 Rayleigh, 141
 Read, 91
 Rice, 140
 Rimmer, 179
 Ritschl, 122-124, 126
 Rochester, 44, 48, 72, 204, 207, 216, 223,
 228, 231, 248
 Rodden, 133, 209
 Rodebush, 200
 Rompe, 121
 Rosen, 80, 102, 110, 120, 127, 130, 149,
 192, 214, 218-220, 239, 240
 Rosenthaler, 55
 Rudnick, 160
 Rydberg, 48, 114, 145
 Ryde, 87

SAMUEL, 220, 222
 Sastry, C. R., 45, 146
 Sastry, M. G., 146
 Schaafsma, 65
 Schmid, 94, 95, 100, 170, 183, 197
 Schmitz, 118
 Schou, 84, 85
 Schuler, 139
 Schumacher, 74, 118
 Sen-Gupta, *see* Gupta
 Shapiro, 134
 Shin-Piaw, 219, 220, 239, 240
 Shurcliff, 101
 Silverman, 195
 Simon, 205, 229

Simpson, 213
 Singh, 60, 197
 Sinha, 124, 153, 154, 157, 187, 189, 190
 Smith, A. W., 208, 209, 231
 Smith, E. C. W., 178
 Smith, H. D., 196
 Smyth, 99
 Sommermeyer, 121, 122, 154, 155, 188,
 210, 211
 Sparks, 70
 Spinks, 53
 Sponer, 185, 216
 Stein, 119
 Steiner, 195
 Stenvinkel, 248
 Stevens, 197
 Stewart, 82
 Stowell, 238
 Strait, 53
 Straley, 208, 209, 231
 Strong, 56
 Strutt, 168, 170, 182, 198
 Subbaraya, 115, 146
 Sugarman, 83
 Svensson, 114
 Swings, 80
 Szabó, 93

TANAKA, 184, 199
 Tawde, 57
 Terenin, 115, 142, 143, 146, 249
 Terrien, 123
 Thompson, 86, 100, 137
 Thunberg, 57
 Tolansky, 211
 Turner, 161
 Tyrén, 114

UCHIDA, 73, 74, 117, 148, 187, 190
 Uhler, 162
 Urey, 119, 140

VAGO, 207, 208, 226, 231, 232
 Vaidya, 73, 75, 79, 83, 100, 150, 211
 Valberg, 244
 van der Ziel, 169, 172
 Vegard, 170
 Venkateswarlu, 74, 117, 149

WAGNER, 75
 Wahl, 200
 Wahrhaftig, 118
 Wajnkranc, 150
 Walker, 208, 209, 231
 Walter, 112, 141, 148, 154, 155, 157,
 187, 188, 190, 209, 210, 247
 Walters, 61, 65, 102, 107, 162, 233,
 236
 Warren, 149
 Watson, M. C., 49
 Watson, T. F., 46, 127, 230
 Watson, W. W., 64, 65, 67, 68, 106, 116, 133,
 153, 158, 160, 176, 187, 199, 205, 209,
 229, 236
 Weber, 106
 Wechberg, 75
 Wehrli, 131, 132, 143, 144, 148, 150, 151,
 152, 219, 239, 240
 Weizel, 157, 187, 188, 190
 Wenk, 132, 151, 152
 Weston, 99
 Westöo, 68
 Wheeler, 155, 217, 246
 White, 212
 Wieland, 112, 115, 142-144, 146, 148,
 203-205, 247, 249, 264
 Wilhelm, 196
 Wilson, 102
 Winand, 52
 Winans, 142
 Withrow, 206
 Woeldike, 139
 Wolff, 213
 Wolfhard, 193
 Woo, 90, 137
 Wood, 187
 Woods, 124, 137, 224, 225
 Worley, 168
 Wulf, 137, 198, 199
 Wurm, 149, 157

YAMAMOTO, 153
 Yoshinaga, 153, 154
 Yost, 149
 Young, 264
 Yuasa, 48

SUBJECT INDEX

Chemical symbols of molecules are given in the tables of "Individual Band Systems" in alphabetical order and are therefore not included in this index; the chemical symbols given here are ones which are sometimes used as alternatives to those listed in the book.

ABBREVIATIONS, 4, 43

Absorption, 4, 258
 Acetaldehyde, 85
 Acetone, 86
 Acetylene, 80
 Active nitrogen, 168, 180
 Afterglows, 99, 168, 180, 215, 257, 258
 Ammonia, 179
 Ammonia, α -band, 178
 Ammonia flame, 177, 178
 Angstrom bands of CO, 90
 Appearance, 4, 42
 Arc, standard iron, 260
 Arcs, 4, 42, 255
 Atmospheric absorption, 138, 195, 198
 Atomic lines, 2, 254, 265

BANDS, spurious, 262

Benzaldehyde, 86
 Benzene, 81
 Benzene derivatives, 82
 Boric acid fluctuation bands, 60

CAMERON bands of CO, 94

Carbon monoxide flame, 99
 Cathode, hollow, 256
 Chemical symbols, order of, 42
 Collimation, 259
 Comet-head group, $\lambda 4050$, 80
 Comet-tail bands of CO, 97
 Comparison spectra, 260, 264
 Constants, physical, 269
 Continua, 253
 Cool flame bands, 84
 Cyanic acid, 137
 Cyanogen, 90

Cyanogen flame, 87, 177

CHON (*see* HNCO), 137

Ca₂ (*see* CaO), 108, 109

CaC (*see* CaO), 109

DESLANDRES-D'AZAMBUJA bands of C₂, 76

Discharge, high-frequency, 257

ring, 257

tesla, 257

tubes, 256

Discharges, 4, 256

ELECTRON sources, controlled, 257

Electronic transitions, 42

Emel us cool-flame bands, 84

Ethyl bromide flame bands, 74

Ethyl nitrite, 87

Ethylene flame bands, 83

Excitation, states of, 254

Extensive systems, 5

FLAME, 4, 254

Formaldehyde, 84

Formic acid, 83

Formul e for measurement, 261

Fox-Herzberg bands of C₂, 77

GLYOXAL, 86

HIGH-FREQUENCY discharge, 257

High pressure bands of C₂, 76

Hollow cathode, 256

Hydrocarbon flames, 75, 78, 83, 254
 Hydrocarbon flame bands, 83
 Hydroxyl, 140
 HCO (*see* CHO ?), 83
 HCOOH (*see* CH₂O), 84
 HO (*see* OH), 199
 HS (*see* SH), 212

IDENTIFICATION, method of, 1, 253
 Intensities, 3, 254
 Intensity distribution, 3, 4
 Ionisation, 254
 Iron arc, standard, 260
 Isocyanic acid, 137

LINES, atomic, 2, 254, 265
 Lyman-Birge-Hopfield bands of N₂,
 171

MEASUREMENT of plates, 261
 Methyl iodide flame bands, 150
 Methyl nitrite, 86
 Mulliken bands of C₂, 77

NEGATIVE glow, 256
 Nitrogen, active, 168, 180, 257
 Nitrogen, Third Positive bands (*see* NO),
 182
 NO₂ (*see also* HNO₂), 137, 185

OCCURRENCE, 4, 42
 Order of chemical symbols, 42

PERSISTENT atomic lines, 265
 Persistent band heads, 3
 Pfund standard arc, 260

Photographs, use of for identification, 253
 Physical constants, 269
 Plates, description, 263
 Polarised light, spurious bands due to, 262
 Positive column, 256
 Pressure, effect of, 255, 256
 Procedure for identification, 1, 253
 Propionaldehyde, 85

RARE gases, effect of, 256
 References, abbreviations, 43
 Resolving power for absorption, 259
 Rowland angstroms, 268

SCATTERED sunlight, 262
 Schumann-Runge bands of O₂, 3, 5,
 193
 Schuster band of NH₃, 179
 Slit-width, 253, 259
 Sources, 4, 42, 254
 Spark, 258
 Spurious bands, 262
 Swan bands of C₂, 75

TRANSITIONS, electronic, 42
 Triplet bands of CO, 93

VACUUM arc, 4, 255
 Vacuo, wave-lengths in, 268
 Valve oscillator discharge, 257
 Vegard-Kaplan bands of N₂, 170

WATER, 138, 139, 140
 Wave-lengths, 3
 conversion air to vacuum, 268
 measurement of, 261