ON THE PRESENCE OF PHOSPHORUS IN THE SOLAR ATMOSPHERE

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ABSTRACT. Continuing the previous work of the author on the band spectrum of phosphorus, the presence of the P_2 molecule in the solar atmosphere is discussed by a study of the coincidences of the lines of two of its strong bands, (8, 27) and (9, 28), in the near ultraviolet, with the Fraunhofer lines. It has been concluded that the molecule of phosphorus exists in the Sun.

The band spectrum of phosphorus presents several extremely interesting features. The P_2 molecule has an extensive and typical band spectrum ranging from $\lambda 3500$ to $\lambda 1900$ corresponding to a $^1\Sigma - {}^1\Sigma$ transition. The bands are degraded towards the red, possess a simple rotational structure and exhibit an alternation in intensity of the rotational lines which is a well-known characteristic feature of all symmetrical molecules. In recent papers (Rao, 1943*a*, 1943*b*), the author has described experiments leading to the analysis of the P_2 bands in the region about $\lambda 2800$, and the determination of the nuclear spin of the P_2 molecule. In continuation of this work, it was thought worthwhile to see for the possible correlations between the Fraunhofer lines and the lines due to the P_2 molecule in the near ultraviolet region. Also, it is known that a large proportion of faint solar lines (*i.e.*, those having intensities between 1 and -3 on the Rowland scale) is still unidentified and that many of these lines must be of molecular origin.

While discussing the presence of phosphorus compounds in the solar atmosphere Dorothy N. Davis (1941) excludes the study of the P_2 molecule, because the strong bands of the molecule lie in the inaccessible region, but concludes that the molecule of CP may be present in the sun. It is no doubt a fact that most of the strong bands of the molecule of phosphorus fall in the region beyond $\lambda 2800$ which are of no astrophysical importance. But the (8, 27) and the (9, 28) bands, which lie in the near ultraviolet are no less strong than those that are lying in the far ultraviolet, permit a study of the presence of the molecule of phosphorus in the solar atmosphere.

These bands have been photographed by Ashley (1933) in the 2nd order of a 21-foot concave grating for studying the rotational structure of certain bands due to the P_2 molecule and determining the nuclear spin from the alternating intensity ratio. In view of the high dispersion of the instrument used

by Ashley, the wavelengths of all the lines recorded by her in the two bands are used by the author and compared with those of the Fraunhofer lines in the Rowland tables. Differences of not more than 0.04 A between the laboratory measurements and the solar wavelengths have been reckoned as coincidences.

The results are summed up in the following tables—

TABLE I

(8, 27) Band

$\lambda(P_2)$	λ (sun)	$\Delta\lambda = \lambda(\text{sun}) - \lambda(P_2)$	Intensity of the solar line	Identification in the Rowland atlas	$\lambda(P_2)$	λ (sun)	$\Delta\lambda = \lambda(\text{sun}) - \lambda(P_2)$	Intensity of the solar line	Identification in the Rowland atlas
B-branch					3170.44	3170.48	0.04	−1	—
3166.43	3166.44	0.01	1	Fe	3170.66	3170.71	0.05	1	−Ni*
3166.57	3166.60	0.03	0	Zr	3170.90	—	—	—	—
3166.72	3166.68	−0.04	1	—	3171.16	3171.14	−0.02	−2	—
3166 80	3166.77	−0.03	0	—	3171.41	3171.36	−0.05	2	Fe
3166.89	3166.87	−0.02	−2	—	3171.69	3171.67	−0.02	1	Fe
3166.99	3166·99	0.00	−1	—	3171.95	3171.94	−0.01	−2	*—
3167.10	—	—	—	—	3172.25	3172.30	0.05	0	—
3167.21	3167.18	−0.03	1	OII	3172.51	3172.51	0.00	0	—
3167.33	3167.30	−0.03	−3	—	3172 83	3172 85	0.02	−2	—
3167.47	3167.42	−0.05	−2N	—	3173.15	3173.21	0.06	0	OII?
3167.60	3167.60	0.00	−1N	Zr⁺	3173.45	3173.41	−0.04	1	Fe
3167.88	3167.86	−0.02	3	Fe	3173.75	—	—	—	—
3168.02	3168.05	0.03	−3	Co?	3174.10	3174.06	−0.04	−1	—
3168.19	3168.15	−0.04	2	V⁺	3174.43	3174.38	−0.05	0	OH
3168.55	3168.53	−0.02	4	Ti⁺	3174 77	3174.79	0.02	−3	—
3168.71	3168.67	−0.04	0	OII?	3175.13	3175.17	0.04	−3	—
3168.92	3168.96	0.04	1	OH	3175.48	3175.45	−0.03	2	Fe
3169.12	3169.08	−0.04	−2	—	3175.84	3175.82	−0.02	−3	—
3169.31	3169.37	0.06	1	—	3176.23	—	—	—	—
3169.51	—	—	—	—	3176.50	3176.45	−0.05	−1	Fe?
3169.73	3169.75	0.02	1	Co	3176.76	3176.84	0.08	−2	Hf⁺?
3169.95	3170.01	0.06	−3	—	3177.14	3177.08	−0.06	−1	Mn?.
3170.18	3170.13	−0.05	−1	—	3177.54	3177.543	0.003	2	−Fe⁺

TABLE I (contd.)

(8, 27) Band (contd.)

$\lambda(P_2')$	λ (sun)	$\Delta\lambda = \lambda(\text{sun}) - \lambda(P_2')$	Intensity of the solar line	Identification in the Rowland atlas.	$\lambda(P_2')$	λ (sun)	$\Delta\lambda = \lambda(\text{sun}) - \lambda(P_2')$	Intensity of the solar line	Identification in the Rowland atlas.
3178.03	3178.02	−0.01	2	Fe	3172 15	—	—	—	—
3178.45	3178.43	−0.02	−1	..	3172.42	3172 38	−0.04	−3	—
3178.78	3178.79	0.01	−2d	—	3172 73	3172.72	0.01	−3	Ti
3179.21	3179 17	−0.04	−2N	Cr? −	3172.99	3173.00	0.01	1	OH
3179.69	3179.67	−0.02	−2N	...	3173.33	—	—	—	—
3180.13	3180.12	−0.01	−1N	—	3173.62	3173.61	−0.01	1	Fe+ ?
3181.00	3180.99	−0 01	−2	..	3173.97	3173.95	−0.02	−2	—
3181.49	3181.53	0.04	1	Fe	3174 28	3174.22	−0.06	0	—
3181.95	3181.91	−0.04	1	Zr+	3174.62	3174.70	0.08	2	—
3182.93	3182.99	0.06	3	Fe OH	3174 99	3174.95	−0.04	1	Co—
P branch	—	—	—	—	3175.32	3175.32	0.00	1	OH-Fe ?
3167.83	3167.79	−0.04	1	..	3175.65	3175.71	0.06	−3	Mn
3168.16	3168.15	−0 01	2	V+	3176.02	3175.99	−0.03	1	Fe ?
3168.51	3168.53	0.02	4	Ti+	3176.39	3176.35	−0.04	1	Fe
3168.63	3168.67	0.04	0	OH ?	3176.64	3176.60	−0.04	−3	—
3168 87	3168.86	−0.01	1	Fe	3176.96	3176 03	−0.03	−3	—
3169.05	3169 08	0.03	−2		3177 42	—	—	—	...
3169.25	—	—	—	—	3177.93	—	—	—	—
3169.47	3169.43	−0 04	1	—	3178.33	3178.33	0.00	−3	—
3169.66	3169.62	−0 04	0	OH	3178.74	3178.79	0 05	−2d	—
3169.88	3169.86	−0 02	0	OH	3179.14	3179.17	0.03	−2N	Cr ?—
3170.10	3170.13	0.03	−1	—	3179.56	3179.51	−0.05	1N	Fe
3170.58	3170.48	−0.10	−1	—	3180.01	3179.97	−0.04	−1	OH
3170.81	3170.81	0.00	−3	—	3180.89	3180.88	−0.01	−2	—
3171.08	3171.14	0.06	−2	—	3181.34	3181 28	−0.06	3	Ca+
3171.33	3171.36	0.03	2	Fe	3181.81	3181.86	0.05	1	Fe
3171.60	3171.67	0.07	1	Fe	3182.78	3182.81	0.03	0	—
3171.85	—	—	—	—					

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TABLE II

(0, 28) Band

λ (P₂)	λ (sun)	$\Delta\lambda=\lambda(sun)-\lambda(P_2)$	Intensity of the solar line.	Identification in the Rowland atlas.	λ(P₂)	λ (sun)	$\Delta\lambda=\lambda(sun)-\lambda(P_2)$	Intensity of the solar line.	Identification in the Rowland atlas.
R branch									
3184.61	3184.62	0.01	1	—Fe	3189 12	3189.17	0.05	— 3	—
3184.70	---	---	---	---	3189.38	3189.32	—0.06	0	OH
3184.78	3184.76	0.02	·3	—	3189 65	3189.64	—0.01	— 3	—
3184.90	3184.90	0.00	2	Fe	3189.93	3189.96	0.03	— 2	Mn
3185.01	3185.02	0.01	1N	—	3190.21	3190.17	—0.04	— 2	—
3185 11	3185.09	— 0.02	- 3	Mo?	3190.50	3190.54	0.04	— 2	—
3185.25	3185 22	—0.03	—3N	—	3190.80	3190.85	0.05	2	Fe-Ti⁺
3185.36	3185.39	0.03	2	V	3191.14	3191 13	—0.01	0	Fe?
3185.51	3185 56	0.05	— 1	—	3191.43	3191.42	—0.01	0	—
3185.63	3185.67	0.04	0	—	3191.74	—	—	—	—
3185.80	3185.80	0.00	—2N	—	3192.08	3192 04	—0.04	— 1	—
3185.95	3185.98	0.03	0	Co-	3192.75	3192.73	—0.02	— 2	OH
3186.12	3186.11	—0.01	oNd?	OH	3193.10	3193.06	—0.04	— 1	OH
3186.32	3186.27	—0.05	— 1	—	3193.41	—	—	—	—
3186 47	3186.45	—0.02	1	Ti	3193.82	3193.82	0.00	1N	Fe⁺
3186.66	3186.64	—0.02	— 3	—	3194.24	3194.24	0.00	— 1	Ti⁺?
3186.84	3186.80	—0.04	1	—	3194.55	3194 53	—0.02	— 1	—
3187.03	3187.06	0.03	—3	—	3194.98	3194.97	—0.01	— 1	Cb⁺
3187.24	—	—	—	—	3195.32	3195.41	+0.09	—2N	—
3187.45	—	—	—	—	3195.65	—	—	—	—
3187.67	—	—	—	—	3196.10	3196.11	0.01	— 3	Fe⁺
3187.90	3187 90	0.00	—3	—	3196.33	3196.34	0.01	— 2	—
3188.13	—	—	—	—	3197.35	3197.36	0.01	— 3	—
3188.37	3188 38	0.01	0	Co	3198.22	3198.28	0.06	0	—
3188.61	3188.55	—0.06	6d?	V⁺—Fe	3199.13	3199.14	0.01	0	OH?
3188.85	3188.82	—0.03	2	Fe	3200.05	3200.14	0.09	— 1	—

In Tables I and II, in the intensity column 'N' indicates that the line is not clearly defined. Such a line may be considered as composed of two or

TABLE II (contd.)

(9, 28) Band (contd.)

λ (P₂)	λ (sun)	$\Delta\lambda = \lambda(sun) - \lambda(P_2)$	Intensity of the solar line.	Identification of the Rowland atlas.	λ(P₂)	λ (sun)	$\Delta\lambda = \lambda(sun) - \lambda(P_2)$	Intensity of the solar line.	Identification in the Rowland atlas.
P-branch					3191.20	3191.31	0 02	-2	Co
3186.56	--	---	—	..	3191.60	3191 57	-0.03	-3	.
3186.67	3186.64	-0.03	-3	---	3191 93	3191.89	-0.04	-1	NiZr⁺
3186.76	3186 75	-0.01	3	Fe⁺	3192.23	3192.27	-0.04	0	Ti⁺?
3186.82	3186 80	-0.02	1	—	3102.50	3192.62	0.03	-1	—
3187.24	—	—	—	—	3192.94	3192.92	-0.02	1N	Fe?
3187.38	3187.31	-0.07	1	Fe⁺	3193.28	3193 30	0 02	2	Fe
3187.59	3187.56	-0.03	0Nd?	..	3193.59	3193.55	-0.04	-2N	—
3187.82	3187.90	0.08	-3	—	3194.00	3193.98	-0.02	-2	Mo
3188.04	3188.04	0.00	1	Cr?	3194.38	3194.34	-0.04	-3	...
3188 27	3188.20	-0.07	-3	—	3194.75	3194.76	0.01	-2	..
3188.51	3188.54	0.03	6d?	V¹-Fe	3195 13	3195.14	0.01	-1	-
3188.76	—	—	—	—	3195 52	---	—	—	—
3189.01	3188.94	-0.07	-2	—	3195.92	3195.88	-0.04	-3	—
3189.28	3189.32	0.04	0	OII	3196.33	3196.34	0.01	-2	—
3189.54	3189.50	-0.04	-IN	—	3197.16	3197.21	0.05	-2	—
3189.81	3189.82	0.01	-2	—	3198.02	3198.02	0.00	0	V
3190.10	3190.10	0.00	I	—	3198.90	3198.9.	0.00	-2N	Fe?
3190.39	3190.40	0.01	-2	—	3999.82	3199.82	0.00	-3N	V?
3190.68	3190.68	0.00	2	V⁺dFe	3200.77	3200.79	0.02	2	Fe
3190.98	3190.90	-0.08	3	—	3201 76	3201.72	-0.04	-2N	Co⁺

more lines too close to be separated. And two lines close enough together to be considered double are indicated by a 'd', and a double whose components are very difficult to separate is indicated by a 'd?' A '—' before an element say Ni (refer* mark, in the 8, 27 band) means that Ni line is coincident with the red side of the line, the origin of the rest of the line being unknown. Similarly '—' after the element means that the origin of the red side of the line is not known.

From the above tables, we see that, in most cases where there is a large difference in wavelength between the laboratory measurement and the value of the solar line taken from the Rowland atlas, either the solar line is a blend of two or more lines which are too close to be separated or a strong atomic line

in the vicinity masks the fainter molecular line. Also, we find that when the origin of the red or violet part of the solar line is unknown the P_2 line coincides with that particular portion.

Further, it is instructive to compare the observed coincidences with the number which may be expected from chance using the formula of Russell and Bowen (1929),

$$ C = N(1 - e^{-2M x/I}), $$

where N is the number of solar lines in the wavelength interval I, M is the number of lines being investigated for coincidence in the interval I and x is the size of coincidence in Angstrom units. Attention has been paid to possible systematic differences, the numbers of coincidences being determined within 0.01, from 0.01 to 0.02, 0.02 to 0.03 and 0.03 to 0.04 Angstrom units. The results obtained are summed up below :

	(8, 27) band	(9, 28) band
1 Total number of lines in the P spectrum	100	93
2 Observed coincidences (with previously identified and unidentified lines in the solar spectrum)	67	66
3 Observed coincidences with previously unidentified lines	11	15
4 Number of coincidences from chance	49	47

Band (v', v'')	Size of coincidence in Angstroms	Number of chance coincidences	Number of observed coincidences
8, 27	0.01	11	19
	0.01-0.0	13	14
	0.2- 5	12	14
	0.3-0.04	10	10
9, 28	0.01	14	27
	0.01-0.02	12	12
	0.02-0.03	11	13
	0.03-0.04	10	14

We can see from these two tables that in all the cases the number of observed coincidences is more in excess of that expected by chance. Also we find that about 66% of the observed coincidences are with lines previously unidentified. And a large majority of the lines coincide with faint solar lines.

These considerations, in addition to the study of the possible correlations dealt with in the beginning, indicate that with the data at present available we can conclude that the molecule of phosphorus exists in the solar atmosphere.

This conclusion is supported from physical considerations as well. The P_2 molecule is stable enough for the temperature existing in the solar atmosphere as its heat of dissociation is 5.1 volts.

REFERENCES

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Russell and Bowen, 1929, *A. P. J.*, **69**, 196.
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DIELECTRIC CONSTANT MEASUREMENTS

(a) *The Oscillators*—For the wavelength range from about 270 cm. to 1500 cm. an ordinary regenerative type of oscillator was employed. For the shorter wavelengths, 80 cm.—240 cm., a midget 'Acorn' tube was employed in a Hartley circuit. In the latter case, the inductance of the oscillator circuit was a single turn of copper wire of varying sizes in the wavelength range: 80 cm.— 160 c.m. and was of two turns of copper wire of varying sizes in the range : 160 cm.—240 cm.

(b) *Experimental Method and Details*—The discharge tube A was fixed in a vertical position between two thin cylindrical metal pieces held tightly round the outside of the discharge tube. The distance between the two aluminium electrodes of the discharge tube was 7·4 cm. The diameter of the tube was 2.55 cm. and the diameter of each electrode was 2·3 cm. The cylindrical pieces, each of which was 3.5 cm. in length and 2.6 cm. in width, when straightened out, made up the terminal condenser of a pair of Lecher wires. The Lecher wires consisted of No. 18 copper wire spaced at 5.6 cm. Ultra-high frequency oscillations were then induced into the Lecher system from one or the other of the oscillators and resonance adjustments were made by sliding a short-circuiting bridge B, across the wires. The short-circuiting bridge was made of No. 14 copper wire and was mounted on a long handle. The lower side of the short-circuiting bridge was filed to give a sharp edge. A scale was kept horizontally fixed on one side of the Lecher wires and a pointer P fixed to the short-circuiting bridge indicated accurately the position of the bridge when adjusted for resonance. The resonance was indicated by a valve-detector with a galvanometer in the anode circuit. The anode current was balanced for no signal. The detector unit was coupled to the Lecher system at the input end by means of two small condensers *a* consisting of short brass tubes insulated from the Lecher wires by glass sleeves. The diagram of the entire experimental arrangement is shown in Fig. 1. The short-circuiting bridge is sketched in the same diagram. It should be noted that the bridge adjustment was made for voltage maximum across the terminal condenser of the Lecher system.
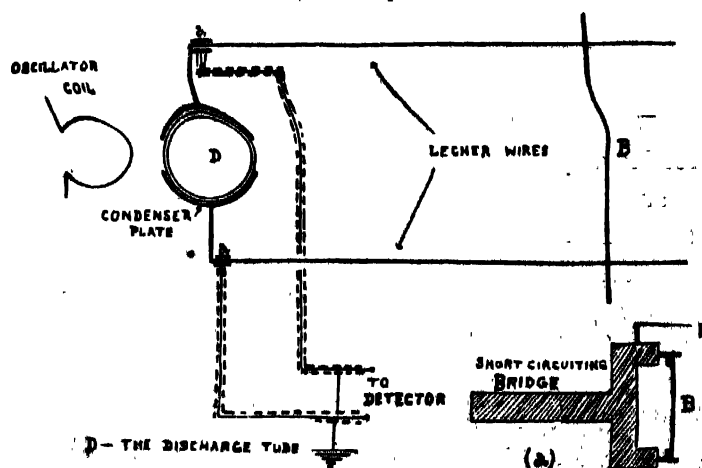
FIG. 1

Careful shielding arrangement was found essential to eliminate the induction effect of the small Rumkorff coil used for passing high voltage discharge through the discharge tube. The induction coil was enclosed in a shielded box and placed at a considerable distance from the experimental arrangement. The leads from the secondary terminals of the induction coil were properly shielded, and so also the leads from the input side of the Lecher wires to the valve-detector. The method of measuring the dielectric constant of the ionized air consisted mainly in determining the tuning position of the short-circuiting bridge when there was no discharge through the tube and in noting the shift of the tuning position when the discharge was passed through the tube.

(c) *Calculation of the effective dielectric constant of the ionized air.*—Let l be the length of the Lecher wire measured from the input end to the resonance point, when there is no discharge. C_0 is the capacity of the condenser which changes to the value $\epsilon.C_0$ (ϵ being the dielectric constant of the ionized air) on passing a discharge through the discharge tube. C_1 is the equivalent capacity of the two condensers with air and glass as dielectrics between the cylindrical pieces and the innei glass surface of the discharge tube. C_2 is the capacity inserted in parallel to C_0 and C_1, in order to make up for the fact that some lines of force between the cylindrical pieces do not actually pass through the discharge tube. It would also be taken to include the capacity and induction effect of the short leads to the cylindrical metal pieces.

When the length of the Lechei wire is adjusted for resonance, we have,

$$\frac{\gamma}{C} \cdot \frac{2\pi}{\lambda} \cdot \tan \frac{2\pi l}{\lambda} = 1 \qquad \dots \ (1)$$

where γ is the equivalent capacity of the terminal condenser, C the capacity per unit length of the Lecher system and λ the wavelength of the standing waves along the wires. Here

$$\gamma = C_2 + \frac{C_1 C_0}{C_1 + C_0} \qquad \dots \ (2)$$

Again, when a discharge is passed through the discharge tube, and if l' be the new resonance length of the Lecher wires from the input end we have,

$$\frac{\gamma'}{C} \cdot \frac{2\pi}{\lambda} \cdot \tan \frac{2\pi l'}{\lambda} = 1 \qquad \dots \ (3)$$

where

$$\gamma' = C_2 + \frac{\epsilon C_0 C_1}{C_1 + \epsilon C_0} \qquad \dots \ (4)$$

Now let us put $\frac{\gamma'}{\gamma} = \epsilon_u$, where ϵ_u stands for the uncorrected value of the di-electric constant of the ionized air. Thus

$$\epsilon_u = \frac{\gamma'}{\gamma} = \frac{C_2 + \dfrac{\epsilon C_0 C_1}{C_1 + \epsilon C_0}}{C_2 + \dfrac{C_0 C_1}{C_1 + \epsilon C_0}} \qquad \dots \ (5)$$

From (5) it can be easily shown

$$\epsilon = \epsilon_u \cdot \frac{C_1}{(1-\epsilon_u)C_0 + C_1}$$

Writing δ for $(1-\epsilon_u)$, we have finally

$$\epsilon = \epsilon_u \frac{C_1/C_0}{\delta + C_1/C_0} \qquad \qquad \dots \quad (6)$$

It is to be noted that C_2 is eliminated from the above expression. Now from (1) and (3),

$$\frac{\gamma'}{\gamma} = \epsilon_u = \frac{\tan \frac{2\pi l}{\lambda}}{\tan \frac{2\pi l}{\lambda}}, \qquad \qquad \dots \quad (7)$$

This ratio $\frac{\gamma'}{\gamma}$ can be experimentally determined and if now we can find the ratio C_1/C_0, the exact dielectric constant of the ionized air can be determined from (6).

(d) *Determination of* C_1/C_0.—Three sets of observations are necessary for the evaluation of this ratio : (i) with only air in the discharge tube, the resonance length l should be obtained, (ii) with normal solution of potassium chloride * inside the discharge tube the resonance length l_1 should be found and (iii) with a non-polar liquid like benzene having a known dielectric constant, the resonance length l_2 should be again obtained. Thus we have for any wavelength λ *

(i) $\dfrac{\gamma}{C} = \dfrac{1}{\frac{2\pi}{\lambda} \tan \frac{2\pi l}{\lambda}}$,   where $\gamma = C_2 + \dfrac{C_1 C_0}{C_0 + C_1}$,

(ii) $\dfrac{\gamma_1}{C} = \dfrac{1}{\frac{2\pi}{\lambda} \tan \frac{2\pi l_1}{\lambda}}$,   where $\gamma_1 = C_2 + C_1$

and   (iii) $\dfrac{\gamma_2}{C} = \dfrac{1}{\frac{2\pi}{\lambda} \tan \frac{2\pi l_2}{\lambda}}$,   where $\gamma_2 = C_2 + \dfrac{K C_0 C_1}{K C_0 + C_1}$,

K being the known dielectric constant of the non-polar liquid. From these three equations, we have again

$$\gamma_1 - \gamma = \frac{C_1^2}{C_1 + C_0}$$

and

$$\gamma_1 - \gamma_2 = \frac{C_1^2}{K C_0 + C_1}$$

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* Pure mercury was also used. Both mercury and the normal KCl solution gave practically the same resonance length.

so that we can write

$$\frac{\gamma_1 - \gamma}{\gamma_1 - \gamma_2} = A = \frac{KC_0 + C_1}{C_0 + C_1}$$

whence

$$\frac{C_1}{C_0} = \frac{K - A}{A - 1} \qquad \qquad \dots \ (8)$$

K is here known and A is obtained from

$$A = \frac{\gamma_1 - \gamma}{\gamma_1 - \gamma_2} = \frac{\dfrac{1}{\tan \frac{2\pi l_1}{\lambda}} - \dfrac{1}{\tan \frac{2\pi l}{\lambda}}}{\dfrac{1}{\tan \frac{2\pi l_1}{\lambda}} - \dfrac{1}{\tan \frac{2\pi l_2}{\lambda}}} \qquad \dots \ (9)$$

The ratio C_1/C_0 can thus be determined.

(c) *Experimental Results.*—The pressure inside the discharge tube at the time of sealing was 3 mm. of mercury. In both sets of experiments for the two wavelength ranges; 80 cm. — 240 cm. and 270 cm. — 1500 cm., the current through the discharge tube was maintained at a constant value, *viz.*, 4.1 m.a. The ratio C_1/C_0 was determined in the manner described in the preceding sub-section.

The dielectric constant values as obtained from (6) and (7) are shown for the shorter wavelength range (80 cm.—240 cm.) in Fig. 2(a). The shift of the resonance point for the same range is illustrated in Fig. 2(b). Similar curves for the longer wavelength range (270 cm.—1500 cm.) are shown in Figs. 3(a) and 3(b),
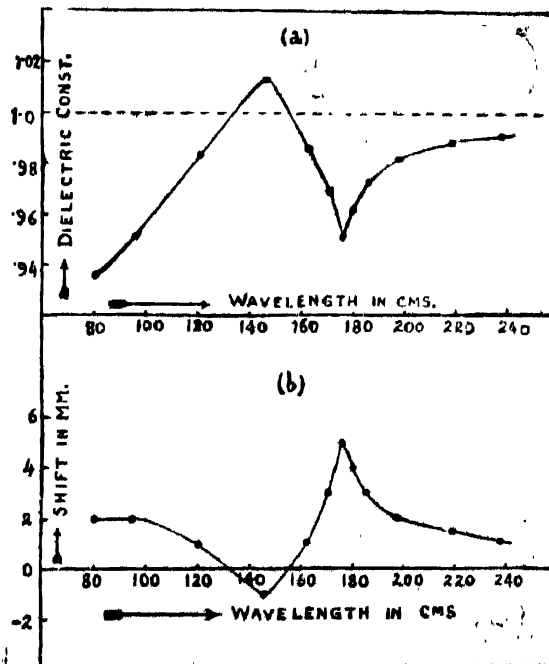
FIG. 2
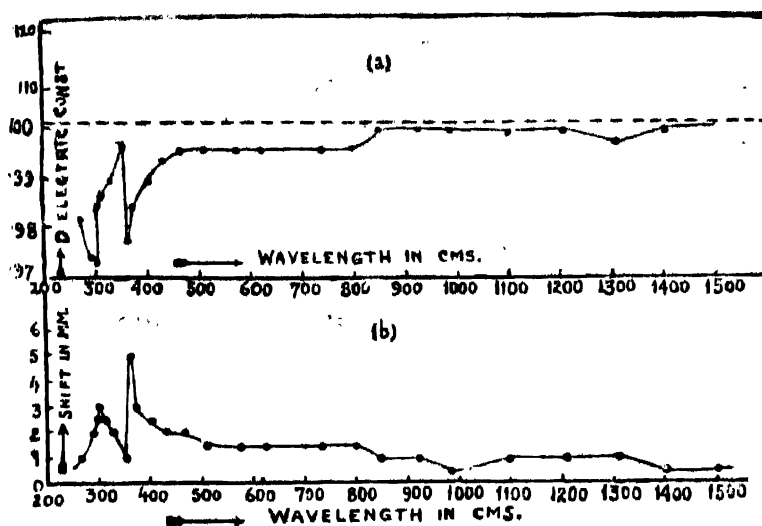
Fig 3.

The most noticeable feature in the observed variation of the dielectric constant of the ionized air with the wavelength of the measuring field is that there were three distinct minima in the dielectric constant value in the following regions:

(1) 175 cm.   (2) 310 cm.   (3) 370 cm.

Proceeding from the shortest wavelength (*i.e.*, about 80 cm. in these experiments) the dielectric constant of the ionized air which was less than unity, was found to increase with the increase of wavelength. It attained the value of unity, when the wavelength was about 130 cm. With further increase of wavelength, the dielectric constant became even greater than unity. Subsequently, the value decreased again showing a minimum at about 175 cm. It increased again remaining however within the value of unity and decreased subsequently attaining a minimum at 310 cm. The dielectric constant similarly increased again remaining always less than unity and later it decreased till a minimum was reached at 370 cm. Subsequently to this minimum, up to 1500 cm. the dielectric constant of the ionized air steadily increased almost approaching the value of unity.   —

DETECTION OF OSCILLATIONS IN THE DISCHARGE TUBE

With the discharge tube working under the same conditions as in the dielectric constant measurements and without working the oscillator, a very careful search was made for the potential nodes on the Lecher wires in order to detect any oscillations in the discharge tube. Evidence of feeble and yet very distinct oscillations at three different wavelengths was obtained. The wavelengths were obtained by measuring the distance between two successive potential nodes. The wavelengths of these oscillations in the discharge tube

were : (1) 169 cm. (2) 310 cm. and (3) 362 cm. The location of the resonance points for the observed oscillations was however less precise. The positions were found to vary by a distance of about 1 cm.

It is interesting that the wavelengths of these oscillations corresponded rather well with the wavelengths, where the minima in the dielectric constant values were observed.

PREVIOUS WORK ON THE OSCILLATIONS IN THE DISCHARGE TUBE

The possibility of a resonance phenomenon in the ionized medium inside a discharge tube had long been envisaged by various investigators. A simple theory of electronic and ionic oscillations inside an ionized gas was developed by Tonks and Langmuir (1929). In the case of the electronic oscillations, the positive ions were supposed to behave like a rigid jelly of uniform positive charge density. Imbedded in it and free to move, the electrons were supposed to have a uniform distribution, so that the net charge was zero. The field arising out of the electron displacement would then be responsible for the displaced electrons to oscillate about their original positions with simple harmonic motion. The frequency of such oscillation would be given by

$$\nu = \left(\frac{Ne^2}{\pi m} \right)^{\frac{1}{2}} = 8980 \sqrt{N},$$

where N is the electron density and e, m are the charge and mass of the electron. Oscillations of this type were called plasma*-electron oscillations.

J. J. Thomson (1931) also developed a similar expression for the frequency of oscillation in the case of electrodeless discharge, *viz.*,

$$\nu^2 = \frac{Ne^2}{\pi m} + \frac{c^2}{\lambda^2}$$

(c being the velocity of light and λ the wavelength of the oscillation). The lower frequency limit for long waves in this case coincides with the plasma-electron frequency of Tonks and Langmuir. Modified expressions for the Thomson formula were given by Jonescu (1931) and Placiteanu (1931). Tonks and Langmuir also considered ionic oscillations and gave an expression for the wavelength of such oscillation.

There was also experimental evidence of oscillations in a discharge tube. Tonks and Langmuir (1929) were able to detect oscillations in specially constructed mercury discharge tubes. The frequency range of the most rapid oscillations (frequency range 300 Mc/s—1000 Mc/s corresponding to the wavelength range, 30 cm —100 cm.) agreed with that predicted for the oscillations of the ultimate electrons. They also obtained evidence of positive ionic oscillations.

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* The word 'plasma' was used by Tonks and Langmuir to designate that portion of the discharge in which the densities of the ions and electrons are high but substantially equal. It comprises the entire space not occupied by ' sheaths ' of positive ions,

Previous to Tonks and Langmuir, Penning (1926) had observed oscillations of radio frequencies in low-pressure discharges in mercury vapour. J. S. Webb, and L. A. Pardue (1928) also described some experiments in which they found oscillations up to 240 Kc/s in a low-pressure air discharge tube.

Gutton (1930 a) postulated the existence of quasi-elastically bound electrons in an ionized gas. According to his idea, the quasi-elastic force has its origin in the mutual action of the ions in the ionized gas at low pressure. The natural wavelength of the electrons under the action of the quasi-elastic force was found to follow the relation :

$$N^{\frac{3}{2}}.\lambda^2 = \frac{4\pi^2 c^2}{A},$$

where N is the electron density, A a constant and c the velocity of light. In an elaborate study of the dielectric properties of the ionized air, Gutton obtained evidence of this natural frequency of the electrons inside a discharge tube, although he was not able to detect any electron oscillation in the ionized medium. The value of Gutton's natural frequency did not however tally with Tonks' and Langmuir's value as required from their formula.

Pederson (1930), on the other hand, explained Gutton's experimental results by regarding the metal plates round the discharge tube and the latter as two condensers in series, one having air and glass as dielectrics and the other having the ionized gas as dielectric. According to Pederson, the latter behaves as if it were shunted by an inductance. The metal plates and the discharge tube in Gutton's experiments were thus equivalent to a circuit of inductance and capacity and it was the resonance of this circuit that Gutton observed. According to this view, therefore, resonance frequency would depend, within wide limits, on the distance between the plates and the discharge tube. Gutton (1930b) however did not notice any such influence.

Resonance dispersion in an ionic plasma was considered by W. Sigrist (1937) as a definite ' container effect,' arising from the decrease of ionic density at the confines of the spatially limited gas discharges. Sigrist made some dispersion measurements in the ionic plasma of a low-potential arc in argon, and obtained evidence of quasi-elastically bound charges with a definite resonance frequency. The experiments of Asami and Saito (1938) in Japan supported Sigrist's view.

POSSIBLE CAUSE OF MULTIPLE RESONANCE OF THE ELECTRONS IN THE PLASMA

A series of overtones in the vibrating system is of course a possible explana-tion (Thomson, 1931, Placiteanu, 1931, Linder, 1936) of the simultaneous appear-ance of electronic oscillations of different frequencies or wavelengths. Alter-natively, according to the view put forward by Tonks (1931), the multiple resonance of the electrons could be attributed to the different electron densities in the plasma. Sometimes, more than one layer are plainly visible at some places inside the discharge tube. In our experiments, it is significant that the 'semi-log'

curves drawn for the determination of the electron density in the discharge tube by Langmuir's probe method, showed indication of a second break, besides the main one which was unmistakable. The main break gave a value of the electron density : $N = .9 \times 10^7$ electrons per c.c. The second discontinuity gave a value : $N = .57 \times 10^7$ electrons per c.c.

The different electron densities in the plasma inside a discharge tube were previously observed by Childs (1930).

RELATION BETWEEN ELECTRON DENSITY AND NATURAL WAVELENGTH OF THE ELECTRONS IN THE PLASMA

Tonks and Langmuir's relation between the electron density N and the wavelength λ of the electronic oscillation would be given by

$$N\lambda^2 = 1.12 \times 10^{13}$$

and if in Gutton's formula $N^{\frac{3}{4}}.\lambda^2 = 4\pi^2 c^2 / A$, we put $A = 6.4 \times 10^{10}$ (which fitted with Gutton's experimental results), then we have

$$N^{\frac{3}{4}}\lambda^2 = 5.5 \times 10^{10}.$$

It is worthy of notice that of the oscillations of three different wavelengths 175 cm., 310 cm. and 360 cm. which were detected in the discharge tube, the oscillation of wavelength 310 cm. appeared to correspond to the electron density $N = .9 \times 10^7$ and the oscillation of wavelength 360 cm. to $N = .57 \times 10^7$; for we find $(N\lambda^2)$ and $(N^{\frac{3}{4}}\lambda^2)$ to remain approximately constant, when calculated with the relevent values of N and λ. Thus

when $\quad N = .90 \times 10^7$, $\lambda = 310$ cm., $N\lambda^2 = 8.63 \times 10^{10}$, $N^{\frac{3}{4}}\lambda^2 = .16 \times 10^{10}$,

and when $\quad N = .57 \times 10^7$, $\lambda = 360$ cm., $N\lambda^2 = 7.37 \times 10^{10}$, $N^{\frac{3}{4}}.\lambda^2 = .15 \times 10^{10}$.

It is also evident that the experimental values of $(N\lambda^2)$ given above are quite different from the value calculated from Tonks and Langmuir's formula. The value of $(N^{\frac{3}{4}}\lambda^2)$, however, indicated a nearer approach to Gutton's value.

ANOMALOUS VALUES OF THE DIELECTRIC CONSTANT OF THE IONIZED AIR

Following Lorentz, the dielectric constant of an ionised gas can be written in the form :

$$\epsilon = 1 - \frac{4\pi N e^2 (\omega^2 - \omega_0^2)}{(\omega^2 - \omega_0^2) + \omega^2 \nu^2}$$

where
ω = angular freqency of the measuring field
ω_0 = natural angular frequency of the electrons
N = electron density
ν = electron collision frequency

and
e and m are the charge and mass of an electron,

The graphical representation of this equation is the familiar curve of auo malous dispersion. Starting with a large value of ω, if we go on diminishing ω, the dielectric constant, which is less than unity, would gradually decrease and after attaining a minimum value it would increase and attain the value of unity when $\omega = \omega_0$. When ω exceeds ω_0, the dielectric constant becomes greater than unity.

If, however, there are groups of electrons, each having a distinct characteristic frequency, then considering one after another all the dispersion curves, corresponding to the various natural frequencies, it can be seen that the final curve would be a superposed effect and the resultant dielectric constant curve could be of the type actually observed in our experiments. This is illustrated in Fig. 4.
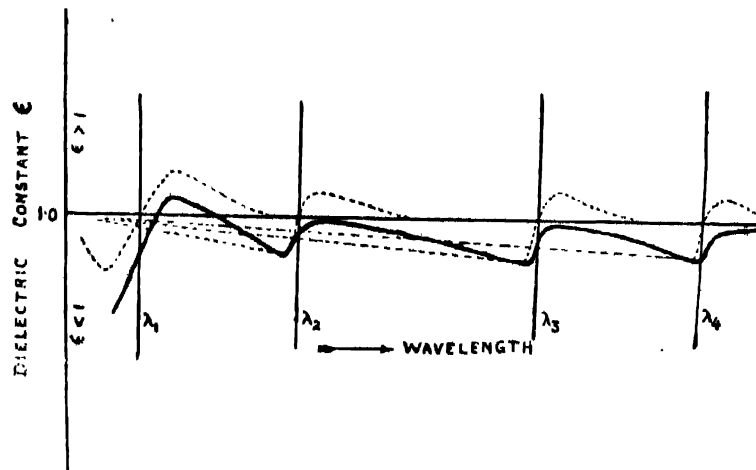
. . . . . . Individual dispersion curve
. _____ Resultant curve

FIG. 4.

Our best thanks are due to Prof. S. N. Bose, Head of the Physics Department, for his interest and help during the course of this investigation.

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