ON THE DIELECTRIC CONSTANTS OF IONISED GASES AT MEDIUM RADIO-FREQUENCY *

By S. R. KHASTGIR, D.Sc.(Edin), Mem.I.R.E.

AND

C. CHOUDHURY, M.Sc.,

Dacca University

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ABSTRACT. Measurements of the effective dielectric constants of ionized air and helium in the discharge tubes by the double-beat method yielded the following results for medium frequencies (1100 kc./sec. to 375 kc./sec.).

(1) When the frequency of the measuring field was fixed, the effective dielectric constant which was found slightly greater than unity increased proportionately with the increase of the discharge current except when the latter was large.

(2) When the discharge current was fixed, the effective dielectric constant decreased gradually with the increase of the wavelength of the measuring field.

The possibility of a resonance frequency of the ionized medium much higher than the frequency employed in this work has been indicated. Accepting such a resonance frequency it would be possible to explain both sets of results according to the classical dispersion formula.

INTRODUCTION

In the present investigation, measurements of the effective dielectric constants of ionised air and helium were undertaken for a frequency range from about 1100 Kc./sec. to about 375 Kc./sec.

Fräulein Szekely [1] was perhaps the only previous worker who carried out similar measurements on medium radio-frequencies. The method she followed was a resonance method with the experimental condenser inside the discharge tube. The effect of the conductivity and also that of the positive ionic sheath were likely to bring in complications in the correct evaluation of the effective dielectric constant of the ionized gas in these experiments. She obtained the values of the dielectric constants of ionized air *always* greater than unity.

In the present investigation external condenser plates were used touching the outer surface of the discharge tube. The discharge was a D. C. discharge with

* Communicated by the Indian Physical Society.

1 Szekely, Ann. der Physik, 5, 3, p. 112 (1929).

the help of an induction coil. The conductivity correction was not therefore necessary. As before two sets of experiments were performed :

1. Variation of the effective dielectric constant of the ionized air and helium for various values of the discharge current for a definite frequency of the measuring field, and

2. Variation of the effective dielectric constant of the two ionized gases for various frequencies when the discharge current was kept fixed.

EXPERIMENTAL PROCEDURE AND DETAILS

The experimental condenser was made up of two cylindrical brass pieces placed round the outer surface of the discharge tube. This external condenser of capacity C_G was connected in parallel with the tuning condenser of capacity C of a suitable Hartley oscillator. The change in the effective capacity of the experimental condenser round the discharge tube when a discharge was passed through the latter was balanced by changing the capacity of an accurately calibrated small variable air condenser of capacity C_A in parallel with C_G and C, so that the total capacity ($C_G + C + C_A$) remained constant. The procedure was as follows : The high-frequency signal from the oscillator was received by an oscillator-detector valve-circuit which was exactly similar to the oscillator circuit. When the detector circuit was nearly in tune with the oscillator, the familar heterodyne whistle was heard in the telephones placed in the anode circuit of the detector. The audio-frequency voltage developed across the telephones was then amplified by a three-valve amplifier and fed into a loudspeaker which gave a loud musical note. On introducing into the same loudspeaker an audio-frequency current from an audio-oscillator capable of producing an intense note of fixed frequency, beats were heard by suitably adjusting the heterodyne frequency. A variable resistance was placed in series with the secondary coil of the audio-oscillator to match the intensity of the heterodyne whistle with that of the audio-frequency note. Adjustments of the variable vernier condenser C_A in the oscillator to produce no beats were then made successively ; *first* when there was no discharge through the discharge tube and *next* when a discharge was passed. In this way the change in the effective capacity of the experimental condenser on ionizing the gas inside it was accurately determined. In the first set of experiments where the frequency of the measuring field was kept fixed, the values of this change of capacity ΔC were determined for various values of the current through the discharge tube and in the second set where the discharge current was maintained at the same value, the values of ΔC were obtained for different frequencies of the measuring field. The actual values of the effective dielectric constant of the ionized gases could, however, be approximately calculated from a knowledge of the ratio of the observed change of the effective capacity of the experimental condenser to the actual capacity-value of the same. The diagram of the experimental arrangement is shown in figure 1.

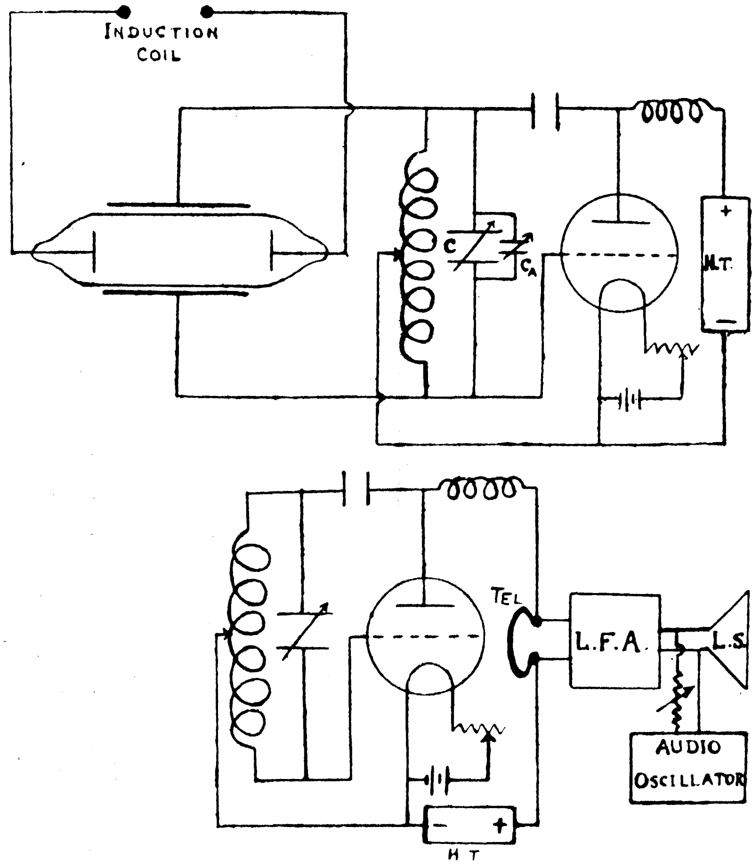

FIGURE I

The tuning condenser C of the Hartley Oscillator and the vernier air condenser C_A were properly shielded.

TABLE I

Air discharge tube

Frequency 428.6 kc/sec. (λ = 700m) Capacity of the experimental condenser : 3·4$\mu\mu f$.

Discharge current (m.a.)	Increase in capacity ($\mu\mu f$)	Dielectric constant ϵ
.25	.05	1.015
.5	.10	1.029
.8	.10	1.047
1.2	.23	1.068
1.5	.26	1.076
1.8	.30	1.082

TABLE II

Helium discharge tube

Frequency 419.6 kc./sec. (λ=715m.)

Capacity of the experimental condenser: 8·5 $\mu\mu f$.

Discharge current (m.a.)	Increase in capacity ($\mu\mu f$)	Dielectric constant ϵ
.25	.053	1.0062
.75	.16	1.019
.8	.21	1.025
1.1	.27	1.032
1.4	.32	1.038

The latter was constructed out of a spherometer. A circular disc formed the fixed plate of this condenser and a similar circular disc placed vertically above and parallel to the former could be pushed by the central leg (which was cut short), when the graduated spherometer disc was given a right-handed turn. On giving a left-handed turn to the spherometer disc, the central leg would move up and the upper circular disc of the vernier condenser could be pulled up by a steel spring suitably fixed. Earthed guard-rings made up of thin brass foils were inserted round the two parallel discs. With two complete revolutions of the spherometer disc, the upper plate would be displaced vertically through 1 mm. and the capacity of the condenser was found to change by 10 $\mu\mu f$. The spherometer disc had a graduated scale with 50 big divisions so that a turn through one such division would mean a capacity-change of 0.1 $\mu\mu f$. Each big division was further divided into 5 smaller divisions. A turn through one small division would cause a change of 0.02 $\mu\mu f$ only.

EXPERIMENTAL RESULTS

(a) *Effective dielectric constant of the ionized gases for different discharge currents for a fixed frequency of the measuring field.*

The results of two typical sets of experiments, one with ionized air and the other with ionized helium are given in tables I & II. They are graphically shown in figure 2. The effective dielectric constant in either case was found slightly greater than unity, *i.e.*, there was an increase in the effective capacity of the experimental condenser on ionizing the gas inside. In the case of helium the discharge current ranged from .25 m.a. to 1.4 m.a. and there was an almost linear relation between the increase of effective capacity and the current passing through the discharge tube. In the case of air, the maximum discharge current was 1·8 m.a. and the increase in the effective capacity of the experimental condenser was found directly proportional to the discharge current up to about

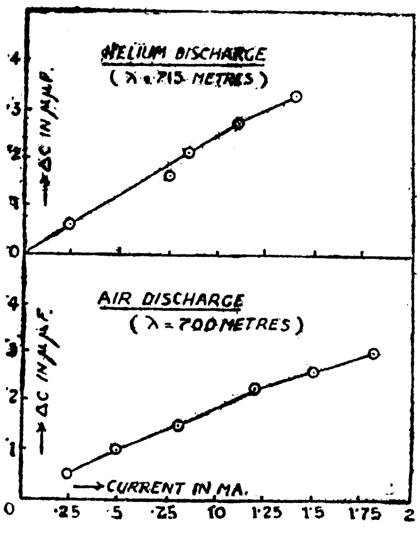

FIGURE 2

TABLE III

Air discharge tube

Capacity of the experimental condenser : 3·4 $\mu\mu f$

Discharge current : .2 m.a.			Discharge current : 1·15 m.a.		
Wavelength (metres)	Increase in capacity ($\mu\mu f$)	ϵ	Wavelength (metres)	Increase in capacity ($\mu\mu . f$)	ϵ
307	·10	1·0294	265	·43	1·126
420	·08	1·0235	310	·41	1·121
480	·07	1·0206	420	·37	1 109
592	·06	1·0177	505	·34	1·100
723	·04	1·0118	645	·30	1·088
825	·03	1·0088	720	·28	1·082
			827	·25	1·074

TABLE IV

Helium discharge tube

Capacity of the experimental condenser : 8·5 $\mu\mu f$

Discharge current : ·2 m.a.		Discharge current : ·75 m.a.	
Wavelength. (metres)	Increase in capacity. ($\mu\mu f$)	Wavelength. (metres)	Increase in capacity. ($\mu\mu f$)
265	.14	315	·40
337	.12	420	·31
433	.10	510	·26
501	.09	623	·22
623	.07	713	·16
781	.05	810	·09
827	.03		

1·25 m.a. beyond which ΔC was found to increase with the discharge current at a slower rate. We can therefore conclude that the effective dielectric constant of ionized air or helium in our experiments increased linearly with the discharge current except when the latter was large.

The wavelength of the measuring field in these experiments was about 700 metres (frequency : 426 kc.). On calculating the value of the effective dielectric constant it was found that the dielectric constant of ionized air varied from 1.015 to 1.082 as the discharge current was increased from .25 m.a. to 1.8 m.a. The calculated value of the effective dielectric constant of ionized helium was found to vary from 1.006 to 1.038 over a range of discharge current from .25 m.a. to 1.4 m.a.

(*b*) *Effective dielectric constants of the ionized gases for different frequencies of the measuring field for a definite ionization value*

The experimental results with air discharge tube for two different discharge currents are given in table III. They are illustrated in fig. 3 where the increase of capacity ΔC is plotted against wavelength of the measuring field for each set of observations. Similar results with the helium discharge tube for two different discharge currents are given in table IV. They are illustrated in figure 4.

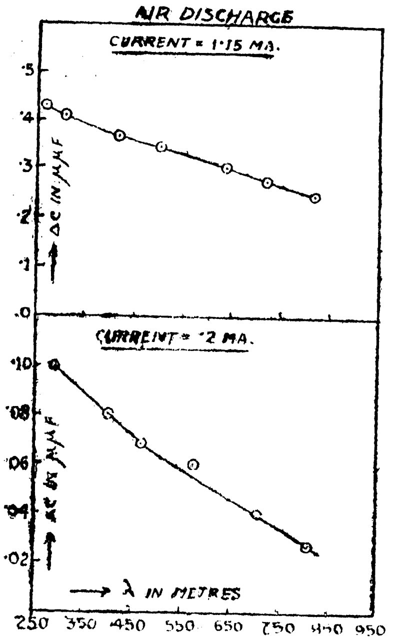

FIGURE 3

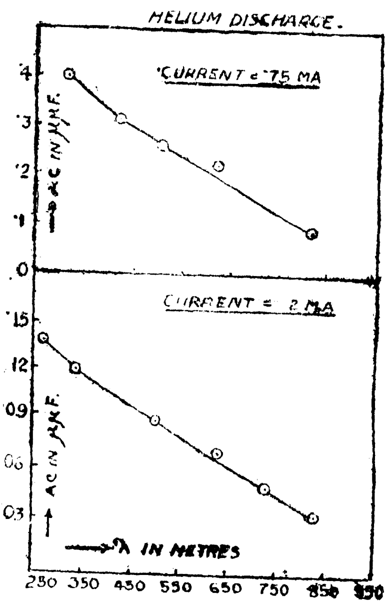

FIGURE 4

For both the ionized gases, the value of ΔC was found to decrease slowly and gradually with the increase of wavelength of the measuring field. This meant that the effective dielectric constant of the ionized gas (air or helium) also diminished slowly and gradually as the wavelength was increased.

It is significant that the effective dielectric constant of the ionized air and helium was *always* found to be slightly greater than unity for medium radio-frequencies. Test experiments were, however, performed with different air discharge tubes having different sizes of electrodes and in all cases the effective dielectric constant of the ionized air was found to be slightly greater than unity. Experiments with the same air discharge tube were also carried out in the ultra-high frequency range, keeping the discharge current at a small steady value and varying the wavelength of the measuring field over some range. For wavelengths smaller than about 9 metres, the effective dielectric constant of the ionized air was found to be definitely less than unity.

DISCUSSION OF THE EXPERIMENTAL RESULTS

It is considered unlikely that within the range of the discharge currents employed in this work, the effect of the positive ionic sheath on the inner surface of the discharge tube could be the explanation of the value of the dielectric constant being greater than unity in the case of medium radio frequencies. For the same discharge current and tube pressure the thickness of the ionic sheath would remain the same and if the value of the effective dielectric constant was found greater than unity for medium radio frequency, the result would be similar for ultra-high frequency also. For very small discharge cu rents, when the sheath effect would be negligible, it was, however, found that the value of the dielectric constant of the ionized air was definitely less than unity in the ultra-high frequency range, whereas for the same discharge current, under exactly similar conditions, the effective dielectric constant was found to be slightly greater than unity. This suggests the existence of a resonance frequency for the ionized medium much higher than the medium radio-frequencies employed in these experiments. Investigation to locate the resonance frequency is in progress.

It may be said that Gutton's quasi-elastic resonance and Tonk and Langmuir's plasma resonance would be both possible in the medium inside a discharge tube. On either view, the resonance frequency would be very much higher than the medium radio-frequencies we employed in this work. Accepting such a resonance frequency and neglecting the Lorentz term, the complex dielectric constant of the ionized gas would be given by

$$\epsilon' = 1 + \frac{4\pi N e^2 / m}{(w_0^2 - w^2) - jwg}$$

where w = angular frequency of the measuring field
w_0 = resonance angular frequency higher than w
g = frictional constant = $m\nu$
ν = collision frequency
N = electron concentration
e = charge on an electron
m = mass of an electron.

Here in this formula w_0 is related to N. If the resonance is the quasi-elastic one of Gutton,

$w_0^2 = A.N^{\frac{3}{4}}$, whereas for the plasma-electronic resonance of Tonks and Langmuir

$w_0^2 = B.N.$* where A and B are constants.

Hence it can be seen from the expression for the dielectric constant that if the frequency w is fixed and the electron concentration is increased by increasing the discharge current, the dielectric constant would increase proportionately except for the higher currents. With higher currents however, N would be greater and consequently the resonance frequency w_0 would be higher. The

* *i.e.*, N. $\lambda_0^2 = 1{\cdot}1 \times 10^{13}$ where λ_0 is the resonance wavelength.

dielectric constant ϵ would therefore assume smaller values than what the linear relationship between ϵ and N would demand. This is exactly what was observed.

Coming to the variation of the dielectric constant of the ionized gases with the frequency of the measuring field when the discharge current was kept constant, the experimental results would be explicable if a resonance frequency, much higher than the measuring frequency, is supposed to exist. According to the expression for the dielectric constant it is evident that the dielectric constant of either ionized gas which is greater than unity would slowly diminish as the frequency w is diminished or as the wavelength λ is increased.

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PHYSICS DEPARTMENT,
DACCA UNIVERSITY.