Radiofrequency Conductivity of Gas-Discharge Plasmas in the Microwave Region

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November 10, 1947

IN connection with a specific application, we have been investigating the conductivity of gas discharges in the microwave region. The problem involves the transmission of low power, very high frequency signals through a coaxial transmission line containing part of a gas-discharge tube as a dielectric gap in the center conductor.[1] The length of this gap is so determined that the radiofrequency signal normally is attenuated at least 40 decibels when the discharge is off.

The conditions established with respect to the signal level are: (1) that the radiofrequency energy be insufficient to accelerate electrons produced in the discharge to inelastic collision levels, and (2) the mean free path of electrons in the discharge be large compared to the amplitude of possible electronic oscillations in the radiofrequency field. Simple theoretical considerations lead, in the steady state, (1) to the use of non-electronegative gases, and particularly to the heavier rare gases such as argon, neon, krypton, or appropriate mixtures of them, and (2) to pressures such that the electronic mean free time be of the order of the period of the incident waves.[2]

The most significant results are presented here. The data shown below are for measurements made with signals of 2000 megacycles per second and power levels below about 1 milliwatt. For these conditions, pressure below 10 millimeters of mercury of the gases cited above gave best results in accordance with the tentative theory. Some typical characteristics of radiofrequency signal attenuation as a function of discharge direct current are shown in Fig. 1. The discharge tubes were so constructed relative to the coaxial line that discharge plasma fills the region of the dielectric gap. For relatively low current discharges, with either normal glow or arc conditions, the attenuation of the incident signal increases beyond the attenuation of the gap in the absence of a discharge. With further increases in discharge current, the attenuation is seen to fall sharply to a low value. This rapidly rising characteristic is suggestive of a resonance phenomenon. This appears to be related to the high frequency electronic plasmoidal oscillations.[3,4] The frequencies of such oscillations are given by $\nu=(Ne^2/\pi m)^{\frac{1}{2}}$, where N is the electron density in the discharge plasma, e, and m are the electronic charge and mass, respectively. Hence, in a discharge plasma one might expect a continuous spectrum of oscillation frequencies limited at the high frequency side by the value of ν corresponding to the maximum electron density. The maximum electron densities deduced from the discharge direct currents at conditions of minimum attenuation of radiofrequency signal (order of 3 decibels) were found to correspond to values of N which, when inserted in the above equation, yield a value of ν approximating the frequency of the radiofrequency signal. It appears that for conditions of maximum conductivity of a radiofrequency signal of frequency ν_s, an oscillation close to that frequency would exist in the conducting plasma

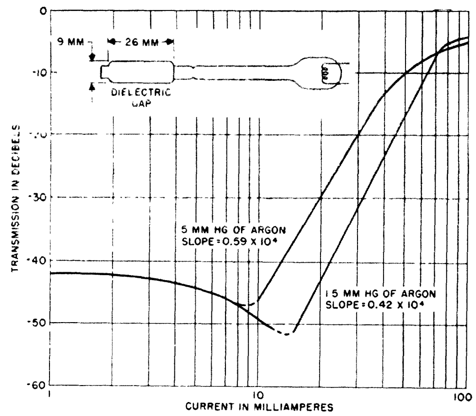

FIG. 1. Typical characteristics of radiofrequency signal attenuation as a function of discharge direct current.

even in the absence of the radiofrequency signal. This led us to investigate the radiofrequency oscillations produced in a direct current gas discharge in the absence of any external radiofrequency fields.

The results of this investigation indicate that such high frequency oscillations do exist in the discharge and have increasing amplitudes with increasing direct currents. In addition to these high frequency oscillations, we observed low frequency oscillations similar to those previously reported.[5,6] These oscillations are classified here, along with random oscillations, as noise. For conditions of minimum attenuation, this noise power was found to be of the order 2×10^{-19} watts/cycle at 2000 megacycles per second.

It may be indicated that this method may be used in the study of the properties of the gas discharge plasma. In particular, information concerning electron densities, electronic mean-free path, and in the disintegrating plasma, the electron distribution functions may be obtained.

[1] D. E. Kerr, S. C. Brown, and W. P. Kern, Bull. Am. Phys. Soc. **22**, 28 (1947).
[2] H. Margenau, Phys. Rev. **69**, 608 (1946).
[3] L. Tonks and I. Langmuir, Phys. Rev. **33**, 195 (1929).
[4] I. Langmuir, Proc. Nat. Acad. Sci. **14**, 627 (1928).
[5] J. D. Cobine and C. J. Gallagher, J. Franklin Inst. **243**, 41 (1947) and the references included therein.
[6] B. Granovsky and L. Bykhovskaya, J. Phys. U.S.S.R. **X**, 351 (1946).

The Radiations from 2.70-Day Au^{198}

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November 21, 1947

THE radiations from 2.70-day Au^{198} have been investigated with photographic and counter recording spectrometers of 10-cm radius. Sources were prepared by irradiating gold foil in the Clinton pile. Kurie plots, made from sources of various thicknesses, all indicate that the maximum energy of the continuous spectrum is 0.970

±0.010 Mev. Also, these plots are linear for energies greater than 0.6 Mev, but below this energy the points gradually rise above the straight line. This effect is observed even with the thinnest source used, 0.25 mg/cm², and consequently it is felt that it is not due to back-scattering or self-absorption. Superimposed on the continuous spectrum are prominent K, L, and M conversion lines from a gamma-ray of 0.408 Mev, and several weak lines from lower energy gamma-rays. The decay of these lines and the continuous spectrum was followed with the spectrometer, and they were found to have the same half-life. The conversion lines were studied with the photographically recording spectrograph, and the results are summarized in Table I.

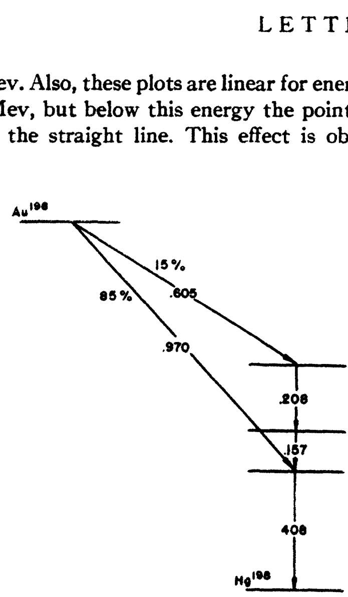

FIG. 1. Suggested decay scheme for 2.70-day Au^{198}.

TABLE I. Gamma-rays and conversion lines in Au^{198}.

Gamma-ray	Conversion lines observed	Estimated intensity of conversion lines	Energy of conversion lines (Mev)	Energy of gamma-rays (Mev)
1	K	Medium	0.074	0.157
	L_{I+II}	Weak	0.144	0.158
	L_{III}	Very weak	0.146	0.158
	M	Faint	0.155	0.157
2	K	Weak	0.125	0.208
	L	Very faint	0.193	0.207
3	K	Very strong	0.326	0.409
	L	Strong	0.395	0.407
	M	Strong	0.407	0.409

The conversion lines of the 0.408-Mev gamma-ray have been observed by several investigators,[1-3] and some of the other lines by Plesset.[2] The value obtained for the maximum energy of the beta-spectrum is considerably higher than the 0.92±0.01 Mev given by Siegbahn.[3] However, he used a very thick source and, as he states, the spectrum he obtained could be considerably distorted.

The gamma-ray data, together with the apparent inflection in the Kurie plot, support the decay scheme shown in Fig. 1. The maximum energies of the two components of the continuous spectrum are 0.970±0.010 Mev and 0.605 ±0.014 Mev. The end point of the low energy component was obtained by subtracting the sum of the energies of the low intensity gamma-rays from the maximum energy of the high energy beta-component. From the position of the inflection point in the Kurie plot we obtained a value for the low energy end point that agrees with, but is less accurate than, the value given above. The intensity of the low energy component is 15 percent, or less. The uncertainty in this figure is difficult to estimate since, in determining it, we had to assume that the back-scattering and absorption in the thinnest source was negligible.

A paper giving full details of this investigation and a discussion of the beta-ray theory involved is in preparation.

[1] J. L. Lawson and J. M. Cork, Phys. Rev. **58**, 580 (1940).
[2] E. H. Plesset, Phys. Rev. **62**, 181 (1942).
[3] K. Siegbahn, Proc. Roy. Soc. **189**, 527 (1947).

Spark Breakdown at Atmospheric Pressure and Above in Relation to Paschen's Law

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November 22, 1947

THE streamer theory of the spark was developed independently by Loeb and Meek[1] and by Raether[2] from 1939–40 and is applicable to sparks at pressures of about atmospheric and above; it depends on ion concentrations. In consequence, as Varney and later Loeb and Meek[1] have indicated, Paschen's law observed for lower pressures and classically accepted as universally applicable, no longer holds. Proof of its failure in spark breakdown studies at higher pressures had been lacking because of inadequacy in range of the past observations until the recent work of Howell, of Trump, Safford, and Cloud, and of Skilling and Brenner at higher pressures and potentials.[4] The semi-quantitative theory of Meek, also set up independently by Raether, was admittedly incomplete in that it was based solely on field distortion produced by the positive ion

TABLE I.

	p (mm)	(cm)	V_s (Trump) in KV	V_s (Meek) in KV
p = 200 lb./in. = 26250 mm ×cm	7000	3.74	830	773.9
	8550	3.075	813	773.2
	10100	2.60	785	772.7
p = 120 lb./in. = 15760 mm ×cm	3878	4.064	528	487.3
	5430	2.896	515	486.6
	6981	2.261	502	486.0
	8532	1.849	487	485.6
	10084	1.565	473	485.2
p = 20 lb./in. = 2627 mm ×cm	775.7	3.378	95	94.3
	2327	1.130	90	93.9
	3878	0.676	87	93.8
	5430	0.485	87	93.6
	6981	0.373	84	93.5
	8532	0.307	82	93.4
	10084	0.260	81	93.4