these gives the degree of forbiddenness F of the emission as a whole.[2]

Table II is constructed from Table I for use where only the F of the emission as a whole is required. Thus, e.g., for a nuclear spin change $0\rightarrow 0$, $J=0$ only, and Table II shows that on the Fermi interaction $F=0$ ("allowed") for parity change "no," and completely forbidden ("yes"); for $1\rightarrow 1$, $J=0, 1, 2$, and on Fermi interaction $F=0$ (no) and 1 (yes), etc.

In a forthcoming paper it will be shown how this formalism can be used to derive the energy spectra and the angular distribution properties of beta-emissions of arbitrary degree of forbiddenness.

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[2] Except that for the pure pseudoscalar interaction $\beta\gamma_5$, F is one unit less, owing to the absence of any terms with $f=0$.

Failure of Paschen's Law and Spark Mechanism at High Pressure

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THE use of air at high pressures as an insulating medium as, for example, with power cables and high voltage apparatus in nuclear physics, has aroused considerable interest in the electric breakdown of gases at high pressure. Investigations have been made by Howell,[1] and more recently by Skilling,[2] Skilling and Brenner,[3] Trump, Safford, and Cloud,[4] and Trump, Cloud, Mann, and Hanson.[5] These investigations have all revealed a pronounced failure of Paschen's law when the gas pressure p was very high, as was the case when working with high voltage and short gap distances. These conditions involved very high fields F at the electrodes.

The recent investigators[2-5] agree that the failure of Paschen's law was due to the significant occurrence of a source of ionization which did not depend on the discharge parameter F/p, being instead a function of F and the nature of the cathode surface. It follows that the electron emission from the cathode must play an important and significant part in the breakdown mechanism, which cannot then be accounted for in terms of gas processes alone. The results of Skilling and Brenner,[3] and those of Trump *et al.*[5] all indicated that the electron emission from the cathode contributed strongly (exponentially in the case of an aluminium cathode) to the prebreakdown current, and this emission became, in fact, the controlling secondary process at the very highest pressures investigated. The mechanism of cathode emission suggested was the field emission of electrons from the cathode at high values of F, but no estimates of the magnitude of the field current under such circumstances have been given.

Prebreakdown cold emission of electrons from the cathode in spark gaps at atmospheric pressure in air has been studied during recent years in this laboratory.[6,7] The effect of different surface conditions was examined when the macroscopic electric intensity at the cathode was $\sim 10^5$ volts/cm, corresponding to breakdown, and it was shown that the surface condition and the previous treatment of the cathode exerted a considerable influence on the rates of electron emission. The electron emission was found to follow the Fowler-Nordheim[8] field law which gives the number of electrons emitted per second i in terms of the electric field F by the relation

$$r=i/F^2=A\ \exp(-6.8\times 10^7\phi^{\frac{3}{2}}/F),$$

where ϕ is the work function of the cathode surface in volts, and F is the field in volts/cm. From this equation estimates of ϕ for the emitting surface and of the emitting area for various values of F and i were made. Cold emission currents of the order of 10^4 and 10^5 electrons/sec were readily produced in the prebreakdown phase. If a value of $\phi\sim 4.5$ ev for the common metals such as nickel is taken, the above equation shows that fields of at least 3×10^7 volts/cm are required to produce the observed emission. However, such emission was obtained with values of the macroscopic field in the gap as low as 10^6 volts/cm. Clearly then, either the microscopic field F at the cathode surface is much greater than the measured macroscopic field in the gap (gap voltage/gap distance), or the work function of the region from which the electrons were extracted is much less than 4.5 ev. Allowing for possible local intensification (up to 10 times[9]) of the field at microscopic points on the surface, estimates of ϕ lay within the range 0.1 ev to 0.5 ev, the emitting area was estimated $\sim 10^{-14}$ cm^2. These values appear to suggest that the electrons were obtained from the surface oxide layer (which is always present on electrodes in air). This result shows that high electron emission is possible by field extraction processes from cathodes in air. For breakdown in very small gaps and high air pressures, this process would be very important, and could predominate as a source of ionization when extremely high pressures (and therefore fields) are employed, just as indicated by measurements in air at high pressures.[1-5] Further, this ionization process depends on the field F and also on the nature of the surface which itself to a certain extent might depend on the air pressure. However, the far most important factor in the mechanism is certainly the field F, so that this ionization process is bound to lead to deviations from Paschen's law, which holds only for processes dependent, not on F, but on F/p.

It is now of interest to consider whether such field processes can influence the secondary ionization mechanism[10] in such a way as to produce a modification of Paschen's law. Trump *et al.*[5] have suggested that the high fields employed in small gaps at high gas pressures may enhance the secondary ionization coefficient γ, and that such enhancement would lead to a lowering of the sparking potential V_s and to failure of Paschen's law. In this connection Germer and Haworth,[11] and Newton[12] have already shown how greatly the efficiency of positive ion electron extraction from metal surfaces is increased in the presence of high electric surface fields, and it is likely that this process of electron extraction would be greatly enhanced if electrons were available from regions of low work function, such as oxide layers.[6,7]

However, there is another aspect of this question. It has been established that considerable field emission is obtainable from oxide layers on a cathode surface, and it is interesting to consider whether the presence of positive ions on such layers could produce an enhancement of the microscopic field there and thus produce increased field emission in accordance with the equation above. The net result of this would be a comparatively high electron emission due to the incidence of the positive ions on the cathode or, in other words, an enhancement of the effective value of γ as compared with the (very low) values found in low pressure work when the field F is low. Our previous results[6,7] have shown how rapidly the electron emission i increases with the field F, so that an enhancement of F due to the presence of positive ions on cathode surface layers could lead to greatly increased electron emission. It should be noticed that such a mechanism outlined above would be taking place during the whole prebreakdown process and would appear as a greatly enhanced γ.

Support for this view has been found from the results of recent work in this laboratory on the enhancement of prebreakdown field emission from the cathode due to the presence of positive ions on the surface. In these experiments, residual ions from a previous spark were swept on to the cathode surface and the resulting emission measured. Owing to the difficulties involved in estimating quantitatively the positive ion concentration at the cathode, it is difficult at present to give an accurate estimate of the degree of enhancement obtained in these measurements. It is not, however, unreasonable to consider that the efficiency of the effective γ-process would be considerably increased by a factor $\sim 10^4$ by the enhanced field emission produced by the presence of the positive ions on thin surface cathode layers. This would be especially the case when there was considerable prebreakdown concentration of positive ions in the gap during the time when the sparking potential was being measured.

This effect could lead to an enhancement of γ of about the order required to account for the observed deviation from Paschen's law.

Owing to the large spread observed in measurements of V_s by Trump *et al.*,[5] and indeed of all other observers in this region,[2–4] it is difficult to make reliable estimates of the values of the γ which were effective in these measurements by applying the Townsend sparking criterion to their values of V_s. This spread probably indicates the extremely high dependence of the total emission on the nature of the electrode surface in the presence of oxide films. However, an approximate estimate indicates that on the basis of the Townsend breakdown criterion, the value of γ must have been enhanced by a factor of at least 10^4 to account for the observed deviations in V_s.

It is, however, significant to note that cold electron emission $\sim 10^4$ times greater than would be expected for clean surfaces has been obtained with macroscopic fields of $\sim 10^5$ volts/cm in the presence of oxide films, so that an effective enhancement of this order of the coefficient γ due to the presence of positive ions of the gas on this oxide layer on the cathode would appear to be not impossible.

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Microwave Spectrum of NO_2

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(Received April 19, 1951)

THE microwave absorption spectrum of gaseous nitrogen dioxide has been observed at approximately 26,660 Mc. The spectrograph employed has been described elsewhere.[1] Stark effect modulation was used throughout. The Zeeman effect was measured by winding a coil of approximately 5000 turns of No. 18 wire on a 4-inch diameter coil form. The coil was centered on $\frac{1}{2}\times$1-in. wave guide such that only 10 percent of the guide was subject to a fringing field. The direction of the static magnetic field was perpendicular to that of the microwave E vector, giving rise to Zeeman transitions of the type $\Delta M=\pm 1$. A slight splitting of one of the lines was observed in the absence of the applied dc field due to the component of the gravitational field parallel to the guide axis.

The observed spectrum of nitrogen dioxide is shown in Table I. The frequency range of the apparatus was from 18,000 to 31,000 Mc. The relative intensities were measured to approximately ± 10 percent. The intensities shown do not indicate the temperature coefficient of any of the lines, but only the relative intensities at each temperature. The fact that both of the sets of triplets arise from the same energy level to within 40 wave numbers was established by the constancy of the relative intensities at the two temperatures. The last column of Table I shows the measurements of the Zeeman effect in weak fields. $\Delta\nu$ represents the splittings of the centers of gravity of the two symmetrically displaced components. These measurements were made with the simultaneous application of Stark and Zeeman effects. The effect of varying the Stark voltages upon each magnetic field splitting was determined, and an extrapolation to zero voltage was made when necessary.

TABLE I. Observed spectrum of NO_2.

Line freq. (Mc)	Rel. int. (30°C)	Rel. int. (−75°C)	$\Delta\nu$(Mc/gauss)
26,647.17	147	143	
26,633.83	149	153	0.21$\underline{7}$
26,619.38	178	183	0.44$\underline{0}$
26,603.65	6	—	
26,577.02	176	184	0.47$\underline{1}$
26,569.21	176	184	0.23$\underline{3}$
26,563.25	144	151	

The NO_2 molecule has a magnetic moment of one Bohr magneton arising from one uncompensated electron spin and an electrical polarity of approximately $\frac{1}{3}$ Debye unit. The lines observed are interpreted as arising from the electric rather than the magnetic moment of the molecule. The various angular momenta involved in the molecule include the angular momentum due to motion of the nuclear framework denoted by **L**, and the electron and nuclear spin momenta **S** and **I**, respectively. The hamiltonian may be written as

$$H=\left[\frac{L_a^2}{2I_a}+\frac{L_b^2}{2I_b}+\frac{L_c^2}{2I_c}\right]+A\,\mathbf{L}\cdot\mathbf{S}+2g_I\beta_I\beta[\mathbf{I}\cdot\mathbf{S}-3r^{-2}(\mathbf{S}\cdot\mathbf{r})(\mathbf{I}\cdot\mathbf{r})]$$
$$+[(16\pi/3)\beta g_I\beta_I]|\psi(0)|^2+2\beta\mathbf{S}\cdot\mathbf{H}. \quad (1)$$

The electronic and nuclear magnetons are denoted by β and β_I, respectively. A is a constant, while $\mathbf{r}$ is the radius vector from the N^{14} nucleus to the free electron spin. The proportionality constant A is a function of L and of K, the axial component of L. This hamiltonian does not include the interaction between the electrical moment of the molecule and the applied electric field giving rise to the Stark effect. The first term is the familiar energy of an asymmetrical top. The second member of (1) represents the interaction between the electron spin and the magnetic field produced by the rotation of the molecule. The third member is the dipolar coupling between the electron and nuclear spins, the fourth is the Fermi overlap term, and the final member is the Zeeman energy.

Quadrupole coupling has been excluded since its value is much smaller than the dipolar term, and the above is intended only as a first, preliminary approximation. The contributions of the magnetic moments appropriate to molecular rotation and nuclear spin to the Zeeman energy are also excluded, as they are extremely small compared with that of the electron spin.

It seems likely that the strong lines of Table I arise from transitions of the type $\Delta F=\Delta J=\Delta L$. The six lines are then ascribed to the six possibilities $J=L\pm\frac{1}{2}$, $F=J-1$, J, $J+1$ for given initial L. In principle, there are other multiplet components where $\Delta F\neq\Delta J$ or $\Delta J\neq\Delta L$, but theory shows that they are so weak that they would scarcely be observed. Any other interpretation appears hard to reconcile with the observed intensity behavior. However, it has not as yet been shown that the observed spacing of the components and the Zeeman behavior can be explained on the basis of the hamiltonian function (1). This problem is being investigated further.

The author is indebted to Professor E. B. Wilson, Jr., for suggesting the problem and to Professor J. H. Van Vleck for much help during the course of the research.

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† This work supported in part by the ONR.
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Remarks on the Optics of Radio Waves

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(Received April 23, 1951)

IT is common practice in optics, primarily in the range of the visible spectrum, to consider an obstacle (e.g., a plane wall) as a *minor* disturbance if its thickness d times 2π is small compared to the wavelength measured inside. This is indeed a correct approximation for all practical cases as long as the index of refraction n