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Power Density Requirements for Airglow Excitation by Gyrowaves [1]

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The original proposal in 1938 for generating an artificial airglow by means of concentrated and powerful gyrowaves is reconsidered and new estimates are made of the powers P radiated from an aerial array of D ideal dipoles which would suffice to enhance the normal brightness of the airglow by specified factors. Other interesting phenomena are mentioned which may be produced in the nocturnal E-region by means of such powerful beams of gyrowaves.

Some 22 years ago [Bailey, 1938a and b] it was shown that it is possible to generate in the lower E-region of the upper atmosphere at night an artificial airglow (or "aurora") by means of a concentrated beam of powerful gyrowaves, i.e., waves of the same frequency as the frequency of gyration of a free electron in the local terrestrial magnetic field H, namely $He/2\pi m$. This frequency is about 1,300 kc/s above London and 1,530 kc/s above Armidale (New South Wales) where experiments which bear on this subject are in progress.

With an appropriate array of 800 horizontal dipoles the mean power required to generate an airglow 50 times as bright as the night sky was estimated to be 500 kw. Also, in a part of the region where the glow is generated the number-density of the electrons was estimated to exceed 50 times the normal density.

The estimated brightness was based on the value 16 v/cm/mm Hg for the reduced electric force X/p found experimentally in the uniform column of an electrical discharge in air at a low pressure p, on the assumed pressure 2×10^{-3} mm Hg at the 92-km level of the ionosphere and on an assumed luminous output of 1 candle/watt (c/w).

New estimates have now been made which are based on the following facts:

(1) In certain glow discharges in nitrogen the reduced "normal" electric force X_n/p is equal to, or less than, 3.25 v/cm/mm Hg [Güntherschulze and Betz, 1933].

(2) In the uniform column of a discharge in nitrogen the value of X/p approaches 4 as the tube radius or pressure is increased [Holm, 1923].

(3) From the uniform column of a discharge in nitrogen at the pressure 0.5 mm and with $X/p=10$ the luminous output L is 0.5 c/w [Bailey, 1938a].

(4) In nitrogen the mean energies V_m of electrons with $X/p=3.25$ and 10 are respectively 1.37 and 1.80 v [Townsend and Bailey, 1921].

(5) The resonance potential V_r of the nitrogen molecule is 6.1 v.

(6) Electrons in air have a mean energy of 1.37 v when $X/p=4$ [Crompton, Huxley, and Sutton, 1953].

From the facts (3), (4), and (5) and the assumptions that when $X/p\geq3.5$ the energies V of the electrons in nitrogen have a Maxwellian distribution [2] and the probability of excitation of light by a colliding electron is proportional to $V-V_r$, we can deduce that with $V_m=1.37$ v the luminous output L of a discharge in nitrogen is 0.08 c/w.

Since 80 percent of air consists of nitrogen we may assume, with little error, that when the electrons in air have the same mean energy $V_m=1.37$ the luminous output is the same as in nitrogen. Hence, by (6), when $X/p=4$ in air containing free electrons then $L=0.08$ c/w.

Since (1), (2), and (4) show that a glow discharge in nitrogen can be maintained when $V_m=1.37$ it follows from (6) that a glow discharge can be maintained in air when $X/p=4$ and free electrons are supplied, by ionization by collision or otherwise, at a rate equal to the rate of loss of electrons by attachment, diffusion, and recombination.[3]

We may therefore conclude that a glow discharge in the ionized air of the nocturnal lower E-region can be maintained by a circularly polarized gyrowave which sets up a local rotating electric field X such that $X/p=4$, where p is the air pressure at the 92-km level corrected to 15 °C. From rocket data we deduce that this value of X is equal to 6.8×10^{-3} v/cm.

In order to generate this gyrowave by means of a radio transmitter on the ground connected to an aerial array of D ideal dipoles the required mean radiated power P is given by

$$P=8.64\times10^{8}\,X^2/D \text{ kw},$$

where X is in v/cm, i.e., by

$$P=40{,}000/D \text{ kw}. \qquad (1)$$

[1] Contribution from Department of Physics, University of Sydney, Sydney, Australia.

[2] Maxwell's distribution is adopted here on account of the discussions of the energy distribution which are given in von Engel [1955], Bayet [1958], and Francis [1960]. Since it relates only to perfectly elastic collisions, Druyvesteyn's distribution is strictly not applicable to electrons in gases like nitrogen and air under the influence of the high-frequency electric forces considered here; for these forces are such that the average loss of energy by an electron at a collision is more than 50 times as large as that lost in an elastic collision. Also several publications by M. Bayet et al., stress the fact that in many experiments involving relatively large electron temperatures (of the order of 30,000 °K) the energy distribution is found to be Maxwellian. For all these reasons it does not seem worthwhile to widen the present discussion to include Druyvesteyn's distribution.

[3] This conclusion is in agreement with some observations made by M. Cutolo on low pressure discharges produced in air in a magnetic field by means of the corresponding gyrowaves (Private communication).

When $D \geq 80$ the power flux density, $cX^2/4\pi$, into the E-region overhead is uniform within 10 percent over an area which subtends at the ground a solid angle of $\pi/4D$ steradians. Within this area the power flux density for $X=6.8\times10^{-3}$ v/cm is 1.22 $\times10^{-7}$ w/cm^2, and so the apparent brightness of this area would be about 10^{-8} candles/cm^2; this is of the same order of magnitude as the normal brightness of the night sky.

Thus the gyrowave radiated with the power P given by eq (1) would enhance the normal brightness by about 100 percent; this is more than 10 times as large as the least enhancement which can be observed visually or by means of a photoelectric device. In particular we may conclude that an array of 80 dipoles radiating a gyrowave with a mean power of 500 kw would produce an easily observable enhancement of the nocturnal airglow overhead within a solid angle of 32 square degrees.

If the transmitter could be made to generate pulses of gyrowaves each of power 3,500 kw and of length about 200 μsec the corresponding value of X/p would be 10.5 and then each resulting flash of airglow would be about 40 times as bright as the night sky.

A constant mean power of 500 kw radiated from an array of 500 dipoles would produce an equally bright steady glow within a solid angle of about 5 square degrees.

Since the existence of the normal airglow and the probable existence of notable ionizing streams of meteors in the E-region suggest that an appreciable fraction of the molecules present may be in excited states, the values of brightness given above may be notably exceeded or else attained with lower values of the product PD.

Other interesting phenomena which may be produced in the nocturnal E-region by such beams of gyrowaves, with similar or larger powers [Bailey, 1959], are as follows:

(1) Generation or enhancement of infrared radiation and of the radiation from sodium atoms.

(2) Making visible parts of overhead meteor trails or the enhancement of such trails when visible.

(3) Enhancement of radar echoes from such trails.

(4) Making visible parts of overhead tracks of solar corpuscles or other extraterrestrial particles.

(5) Production of transient local variations of the terrestrial magnetic field.

The magnitudes of most of these phenomena are not easy to predict, at least because some of the necessary physical data are unavailable. But some support for the conclusions (2) and (4) is provided by the experiments of A. R. Bevan [1949] in which the tracks of α- and β- particles through neon at 200 mm pressure were revealed by the localized glows caused by strong microwave pulses.

Even with less powerful beams of gyrowaves it is possible to make important, though invisible, changes in the nocturnal E-region [Bailey and Goldstein, 1958; Bailey, 1959]. For example, with an aerial array of 40 dipoles and a power of 500 kw the corresponding value of X/p at 92-km height would be about 2.5 and so a pulse of length 2 sec. would notably reduce the rate of attachment of local electrons to molecules and thereby increase the local electron density by a factor of about 5. The theory of this phenomenon also shows that such a pulse can be used to determine experimentally the rates of attachment of electrons near the 92-km level as well as other information about the collisions of these electrons with neutral particles. Preparations are under way at the University of New England in Armidale to carry out experiments with such strong pulses and the use of auxiliary pulses for probing the ionospheric regions modified by the strong pulses.

All these conclusions, together with the work previously accomplished on gyrointeraction, show that experiments with beams of powerful gyrowaves are likely to throw light on several obscure aspects of the ionosphere such as the nature of the neutral and charged constituents of the E-region, the processes which determine the density of ionospheric electrons and some of the processes which cause the natural airglow. Moreover, the possibility of artificially increasing the local electron density in this way may have applications to radio communication.

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References

Bailey, V. A., On some effects caused in the ionosphere by electric waves, Phil. Mag. **26,** 425 (1938a).

Bailey, V. A., Generation of auroras by means of radio waves, Nature **142,** 613 (1938b).

Bailey, V. A., Some possible effects caused by strong gyrowaves in the ionosphere-I, J. Atmospheric and Terrest. Phys. **14,** 299 (1959).

Bailey, V. A., and L. Goldstein, Control of the ionosphere by means of radio waves, J. Atmospheric and Terrest. Phys. **12,** 216 (1958).

Bayet, M., Physique electronique des gaz et des solides, p. 171 (Masson et Cie., Paris, 1958).

Bevan, A. R., High-frequency discharges localized along tracks of ionizing particles, Nature **164,** 454–455 (1949).

Crompton, R. W., L. G. Huxley, and D. J. Sutton, Experimental studies of the motions of slow electrons in air with application to the ionosphere, Proc. Roy. Soc. London **218,** 507–519 (1953).

Francis, G., Ionization phenomena in gases, pp. 91, 92, 135 (Butterworth's Scientific Publications, 1960).

Güntherschulze, A., and H. Betz, Gradienten der Glimmentladung in Röhren und weiten Gefässen und der Begriff "Normalgradient," Z. Phys. **81,** 283 (1933).

Holm, R. (1923). See A. von Engel, Ionized gases, p. 218 fig. 126 (Clarendon Press, 1955).

Townsend, J. S. and V. A. Bailey, The motion of electrons in gases, Phil. Mag. **42,** 873 (1921).

von Engel, A., Ionized gases, appendix 3, pp. 259, 260 (Clarendon Press, 1955).

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