neighbourhood of the connexions, the magnetic field from the supply current predominates over the field from the coil, particles will be reflected and will not be absorbed by the connexions. The field from the supply current gives an additional drift in planes through the z-axis; but since the connexions carry current in opposite radial directions, a cancellation of the drift takes place for particles passing around the z-axis repeatedly. Further, the coil windings will have finite electric conductivity and a stationary electric field will be generated by a potential drop in the φ-direction. This field should be screened by a metal coating around the coil and its connexions.

Charged particles may be injected by sources touching the outer edge of the shaded area in Fig. 1. A slowly decreasing magnetic field may possibly produce an inward drift which prevents the particles from hitting the sources repeatedly.

Confinement at high gas densities is outside the scope of this short communication and requires more knowledge about the stability of the field, the pressure balance and the interactions between particles. The coil windings may act as a metallic wall and have some stabilizing effect on deformations of the magnetic field by motion of the gas. A particle density $n = 6 \times 10^{22}$ m.$^{-3}$, corresponding to a pressure $P \approx B^2/4\mu_0$, gives a reaction time of 15 sec. in the example above. The behaviour of a toroidal induced discharge[3] is of great interest in the present connexion.

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[1] Spitzer, L., "Physics of Fully Ionized Gases" (Interscience Pub., New York, 1956).

[2] Alfvén, H., "Cosmical Electrodynamics" (Oxford Univ. Press, 1950).

[3] Post, R. F., *Rev. Mod. Phys.*, **28**, 347 (1956). *Nucleonics*, 23 (1955); 42 (1956). Carruthers, R., and Davenport, P. A., *Proc. Phys. Soc.*, B, **70**, 49 (1957).

A Travelling-Wave Parametric Amplifier

THE principle of parametric excitation of an oscillatory system has been known for many years. An electric oscillatory circuit can be excited in this way if the condenser plates are instantaneously pulled apart by a fixed amount whenever the voltage reaches a maximum value, and instantaneously restored to their original positions when the voltage is zero. Under these conditions energy is communicated to the circuit when the plates are pulled apart; but none is extracted when they are restored, and so oscillations can be maintained. The capacitance/time graph envisaged in the foregoing is a square wave at twice the resonant frequency of the circuit; but it can be shown that a sinusoidal variation at twice the resonant frequency may be used. Any method of periodically varying the capacitance may be used, or alternatively the inductance may be varied. Moreover, such a circuit can be used as an amplifier, since, at the fundamental frequency, the excitation mechanism is analogous to negative resistance.

In considering the possibility of obtaining a useful amount of parametric amplification at high radio-frequencies, a travelling-wave type of parametric excitation has been studied. It has been found that a loss-less transmission line having distributed inductance per unit length given by:

$$L = L_0[1 + \eta \sin 2(\omega t - \beta x)]$$

and constant distributed capacitance C_0 per unit length will support a growing current wave of the form

$$i = i_0 \exp(\alpha x) \sin(\omega t - \beta x + \varphi)$$

where

$$\alpha \doteqdot \omega\sqrt{L_0 C_0}.\frac{\eta}{4} \cos 2\varphi$$

$$\beta \doteqdot \omega\sqrt{L_0 C_0}\left(1 - \frac{\eta}{4} \sin 2\varphi\right)$$

If $\cos 2\varphi = 1$ the maximum possible amplification is obtained and $\alpha = \omega\sqrt{L_0 C_0}.\frac{\eta}{4}$ nepers per unit length. Under these conditions it is also found that $\beta = \omega\sqrt{L_0 C_0}$.

For example, if $\eta = 0{\cdot}1$, a gain of 1·36 db./wavelength is theoretically obtainable. However, this amplification is only obtained when the frequency ratio is precisely 2, and the correct phase relationship must be preserved if the maximum amplification is desired. Thus, the oscillator used for providing the periodic variation of inductance must be synchronized to the incoming signal.

The noise figure of such an amplifier should be very favourable, and an experimental study is being made. Related schemes, in which precise frequency and phase relationships are not demanded, are also being studied.

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Lattice Image of Twin Structure observed directly by Electron Microscope in a Crystal of Copper Phthalocyanine

RECENTLY, with the increase of the resolving power of the electron microscope, it has become possible to make a direct observation of a crystal lattice composed of large molecules. J. W. Menter[1] succeeded for the first time in observing the lattice structure and the edge dislocation contained in it in crystals of metal phthalocyanines. This method is also applicable to the study of the local variation of the fine structure in a crystal lattice, and the so-called selected area micro-diffraction method, when used jointly with this method, has proved its further usefulness.

As an example of such an application, we have observed directly the twin structure in the crystal lattice of the stable copper phthalocyanine, which has a lath-shaped crystal habit. It is well known that this substance has a crystal structure with space group $P\,2_1/a$ of the monoclinic system, as reported by Robertson[2], and a crystal habit in which generally the (001) plane is the largest habit surface; the crystal lath usually lies on this surface, and the b-axis coincides with the direction of the longest edge of the lath-shaped crystal. The lattice image of the $(20\bar{1})$ plane was observed by Menter with the crystal of such habit. Further investigation has shown that some crystals of the stable copper phthalocyanine frequently acquire another lath-shaped crystal habit in