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G. Marconi

CONTENTS



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# THE MARCONI REVIEW

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# THE APPLICATION OF HIGH FREQUENCY CURRENTS IN MEDICINE AND SURGERY

*In the first part of this article, published in* THE MARCONI REVIEW NO. 51, *some biological principles were briefly discussed and the applications of diathermy and electrosurgery reviewed.*

*In the following and concluding section of the article a description is given of some commercial diathermy apparatus manufactured by the Marconi Company, and the application of ultra short waves to therapy is treated.*

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CONSIDERING now a thermionic valve generator, in Fig. 7, we have the wave form given out by one valve, the plate of which is fed by unrectified high tension current at low frequency, so that the high frequency current generated is modulated by the low frequency, and during about one-half of the low frequency period no high frequency is generated.

Fig. 8 gives an idea of the wave form generated by applying raw A.C. to the plates of two valves which are arranged in "push-pull," which means that first one plate becomes positive and then the other. Here we have space devoid of high frequency indicated by Fig. 7 filled in Fig. 8, but this is far from the ideal, because if the current generated by either of these two types of oscillators were applied to the human body there would be a tendency to decompose the body fluids by electrolytic dissociation caused by the imposition of the low frequency envelope.

The ideal wave form, indicated by Fig. 9, is generated by the Marconi Type M.494 Valve Diathermy apparatus shown in Fig. 10, which has been designed to provide suitable current for medical and surgical purposes, including cutting under water. This machine is being used to the complete satisfaction of some of the leading physicians and surgeons in the largest London hospitals and elsewhere. It is also being used in veterinary surgery.

It provides ample current for the full diathermy treatment of one person, and for all the requirements of the surgeon. Current up to 4.5 amperes can be drawn from the set when the load impedance is low.

The apparatus is housed in a metal cabinet, which effectively screens the set from interfering with wireless reception, and the cabinet is finished by a special electrolytic process, with chromium plated relief, so that it can be kept clean easily by the hospital staff. The control handles are removable for sterilisation.

Its control is so simple that it can be operated by a nurse after a little initial instruction.

For surgical work a foot switch is provided so that the operating surgeon can switch the power on and off by a foot pedal, thus leaving his hands free for his work.

The input is 850 watts, and by means of a plug the unit can be tapped to work off 200 to 250 volts, 50 cycle supplies.

Arrangements can be made to work the apparatus off supplies of other voltages and frequencies, or off D.C. systems.

Smaller models for surgery only, or for therapy only are in course of development.

The Marconi Type M.612, Fig. 11, is a small model valve diathermy unit giving an output of 85 watts at the patient's terminals. It is very suitable for all surgical work, and for therapeutic treatment which involves light currents.

The characteristics of the current are such that a very smooth clean cut is obtained, which can be easily controlled according to the operation in hand.

For therapeutic treatment the patient can be tuned in to resonate with the oscillator.

A foot switch and/or a push switch is provided so that a surgeon can switch the power on or off with his foot, or when a patient is undergoing therapeutic treatment the hand push switch may be placed in a convenient position so that the set can be switched on or off from a distance.

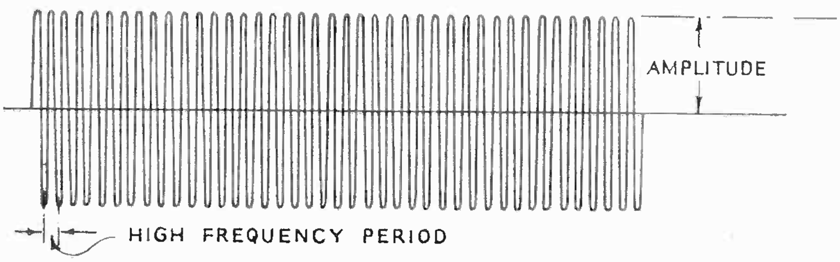



FIG. 9.

The set can be plugged externally to work off 100, 110, 200, 220, 230, 240 or 250 volts at 50 cycles, and a tapping is provided so that it can be run off a small rotary converter where a D.C. supply only is available.

The input is less than 300 watts, so that current can be drawn from an ordinary lighting circuit.

Full wave rectification is accomplished by means of metal rectifiers, and the current is smoothed to a high degree.

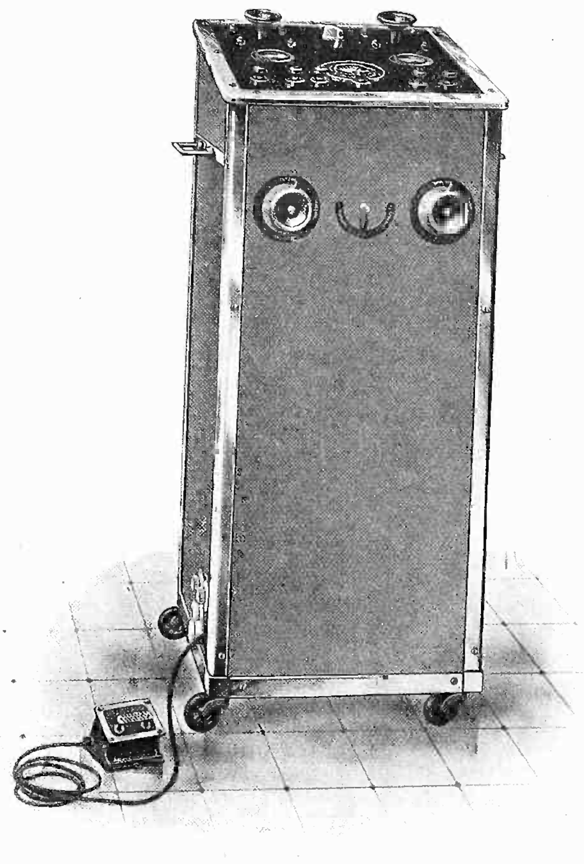
Therefore the only renewals are the two D.E.T.1.SW. valves which are used as oscillators.

This unit is a smaller edition of Type M.494, except that it works at two spot frequencies, one of which is for surgery and the other for therapy.

**Ultra Short Wave Therapy.**

Ultra short waves in the range of about 2.5 to 8 metres are now being used for medical purposes as evidence is accumulating that high frequency currents of these wavelengths have a fundamentally different biological action than currents of wavelengths of the order of 50 metres upwards, as may be expected from what has already been written concerning the physical effects of imposing high frequency fields upon electrolytic fluids.

The method of applying the currents to patients and biological substances differs from medium wave contact electro-therapy, as in the application of ultra short waves the patient is placed in a condenser field generally with air spaces between the patient and the plates as in Fig. 12, but glass and rubber covered electrodes are now coming into use.



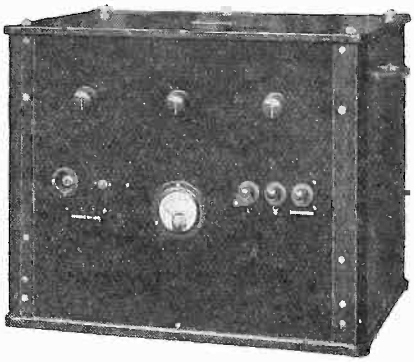


FIG. 11.

FIG. 10.

In the figure, B represents the patient's body, $P_1$ and $P_2$ the condenser plates, and $x/2$ the air spaces.

It has already been explained that the human body has a natural electrical capacity and a pure resistance, so that the equivalent circuit is indicated by Fig. 12 We therefore have a leaky condenser with two air spaces constituting $C_1$ and $C_2$ in series.

So that as Fig. 12 is equivalent to Fig. 13 we have

$$Z_1 + Z_2 + Z_p = Z \qquad \text{(14)}$$

$Z_p$ being the impedance of the body.

Now

$$Z_p = \frac{1}{\frac{1}{R} + j\omega C} = \frac{R}{1 + j\omega RC} \qquad \text{(15)}$$

by rationalising the denominator

$$Z_p = \frac{R - jCR^2\omega}{1 + R^2\omega^2C^2} \qquad \text{(16)}$$

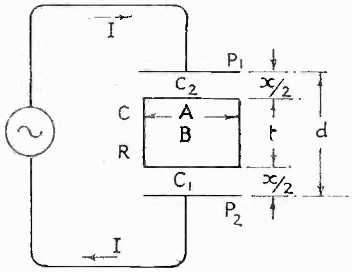



FIG. 12.

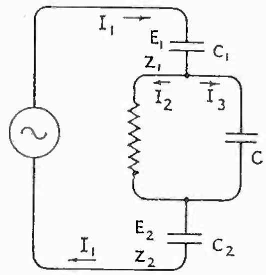



FIG. 13.

If the air spaces are equal $C_1 = C_2$, but for the general case

$$Z_1 = \frac{1}{j\omega C_1} \text{ and } Z_2 = \frac{1}{j\omega C_2}$$

$$\therefore Z_1 + Z_2 = \frac{-j}{\omega C_1} + \frac{-j}{\omega C_2} \qquad \text{(17)}$$

$$\therefore Z = Z_p + Z_1 + Z_2 = \frac{R - j\omega CR^2}{1 + R^2\omega^2C^2} - \frac{j}{\omega C_1} - \frac{j}{\omega C_2}$$

$$= \frac{R - j\omega CR^2 - \left(\frac{j}{\omega C_1} + \frac{j}{\omega C_2}\right)\left(1 + R^2\omega^2C^2\right)}{1 + R^2\omega^2C^2}$$

$$= \frac{R}{1 + R^2\omega^2C^2} - \frac{j\omega CR^2 - \frac{j}{\omega C_1} - \frac{j}{\omega C_2} - \frac{j\omega^2C^2R^2}{\omega C_1} - \frac{j\omega^2C^2R^2}{\omega C_2}}{1 + R^2\omega^2C^2}$$

$$= \left(\frac{R}{1 + R^2\omega^2C^2}\right) - j\left(\frac{\omega CR^2 - \frac{1}{\omega C_1} - \frac{1}{\omega C_2} - \frac{\omega C^2R^2}{C_1} - \frac{\omega C^2R}{C_2}}{1 + R^2\omega^2C^2}\right)$$

$$Z = \sqrt{\left(\frac{R}{1 + R^2\omega^2C^2}\right)^2 + \left\{\frac{R^2\omega\left(C - \frac{C^2}{C_1} - \frac{C^2}{C_2} - \frac{1}{\omega^2R^2C_1} - \frac{1}{\omega^2R^2C_2}\right)}{1 + R^2\omega^2C^2}\right\}^2} \qquad \text{(17A)}$$

Numerically,

and

$$\tan\theta = R\omega\left(C - \frac{C^2}{C_1} - \frac{C^2}{C_2} - \frac{1}{\omega^2R^2C_1} - \frac{1}{\omega^2R^2C_2}\right) \qquad \text{(18)}$$

So that if a sine wave E.M.F. of amplitude $E_o$ is given out by the H.F. Generator then we have at any instant $E' = E_o \sin \omega t$ so that the current

$$I_1 = E_o \frac{\sin(\omega t + \theta)}{Z} \quad \ldots \quad (19)$$

And from Fig. (12) $I_1 = I_2 + I_3$, and $I_2 R = \frac{I_3}{j\omega C}$

$$I_3 = j\omega C I_2 R \quad \ldots \quad (20)$$

and

$$I_2 = \frac{I_3}{j\omega CR} \quad \ldots \quad (21)$$

so that the total voltage across the condenser plates $= I_1 Z$, where $I_1$ at any instant is given by equation (19) and Z is given by equation (17a).

We can also equate $I_1 Z = \frac{1}{j\omega}\left(\frac{I_1}{C_1} + \frac{I_1}{C_2} + \frac{I_3}{C}\right)$ which

$$= \frac{-j}{\omega}\left(\frac{I_1}{C_1} + \frac{I_1}{C_2} + \frac{I_3}{C}\right) \quad \ldots \quad (22)$$

By neglecting the losses due to radiation, which will be considerable unless special precautions are taken to prevent it, and by supposing there are no other losses in the air spaces, we may for our purpose consider only the power spent in the biological substance in the condenser field, which is equivalent to Fig. 14.

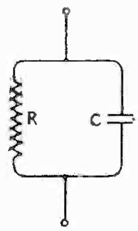



FIG. 14.

So that we have $Z = \frac{1}{\frac{1}{R} + j\omega C} = \frac{R}{1 + j\omega CR}$

$$= \frac{R - jCR^2\omega}{1 + \omega^2 C^2 R^2}$$

by rationalising. ∴ the effective resistance

$$= \frac{R}{1 + \omega^2 C^2 R^2} \quad \ldots \quad (23)$$

and the reactance

$$= \frac{R^2 \omega C}{1 + \omega^2 C^2 R^2} \quad \ldots \quad (24)$$

$$\therefore \tan\theta = \frac{\frac{R^2 C}{1 + \omega^2 C^2 R^2}}{\frac{R}{1 + \omega^2 C^2 R}} = \frac{R^2 \omega C}{R}\left(\frac{1 + \omega^2 C^2 R^2}{1 + \omega^2 C^2 R^2}\right) \quad \ldots \quad (25)$$

$$= R\omega C \quad \ldots \quad (26)$$

If now we suppose that a sinusoidal voltage wave of $E_o \sin \omega t$ and a current wave of $I_o \sin(\omega t + \theta)$ be applied to the substance, then we have at any instant

$$e'i = I_o E_o \sin(\omega t + \theta) \sin \omega t$$

$$= \tfrac{1}{2} E_o I_o \{\cos\theta - \cos(2\,t + \theta) \quad \ldots \quad (27)$$

And if V and I = the r.m.s. value of the voltage and current respectively, then the power spent = VI cos θ
or by Joule's Law the heat H in calories

$$= .24\, I_2^2 RT \qquad (28)$$

where T is the time during which the current $I_2$ flows through R.

Now if in equation (23) $R^2\omega^2C^2 >> 1$ we may write

$$R_{EFF} \doteq \frac{1}{R\omega^2C^2} \qquad (29)$$

and by equating

$$VI_1 \cos\theta = .24 I_1^2 \frac{1}{R\omega^2C^2} \qquad (30)$$

If $f$ is the frequency
we find that

$$H = A\frac{1}{f^2} \qquad (31)$$

where A is a complex function, but which may be fairly constant for a given set of conditions, it will vary with many factors, some of which are almost indeterminate owing to the fact that any experiments to determine them would have to be carried out on animal tissue in its dead state.

The main factors on which the heating effect will depend are :

R specific resistance of the biological substance.
S specific heat.
M mass.
K dielectric constant—owing to the phase angle.
L shape of the body in the field, and
O its orientation.
G cooling effect of the blood in the case of living things.
D heat diffusion in the substance.
U emissivity of the body, and
C heat conductivity.

So that the temperature rise is a complex function of

$$(S\,M\,K\,L\,O\,C\,D\,R\,G\,U) \qquad (32)$$

Here we have

$$M = \rho A t \qquad (33)$$

by referring to Fig. 10, where $\rho$ is the density and A and $t$ are respectively the area and the thickness of the body in the field, and

$$R = \frac{\sigma A}{t} \qquad (34)$$

$\sigma$ is the specific resistance of the substance.

K, as we have seen already, is about 80 for biological substances.

$$C = \frac{Q}{\frac{dT}{dx}} \qquad (35)$$

where Q is the quantity of heat passing through one sq. cm. area and $\frac{dT}{dx}$ is the temperature gradient along a line $x$ normal to the surface, and in considering conductivity for heat we must also consider the conductivity for temperature or the diffusivity

$$D = \frac{C}{\rho S} \qquad (36)$$

C will also depend upon the emissivity of the body,

$$U = \frac{l}{\theta_1 - \theta_2} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (37)$$

where $l$ is the heat loss per sq. cm. of surface of the body, $\theta_1$ and and $\theta_2$ are the internal and external temperatures respectively.

The specific heat, S, will also depend upon the physical state of the substance, which may be partly solid, partly liquid, and partly gaseous in animal tissue.

The variation of specific heat with the physical state of matter is outlined very briefly at the end of the article.

Boundary conditions at the points of separation of different media of the body will also affect the temperature rise.

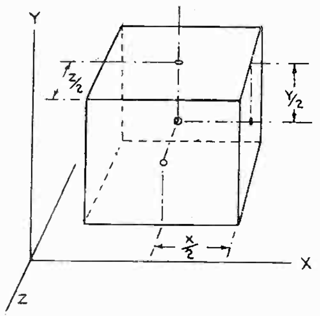



FIG. 15.

If we take a simple case and suppose that we place a body in the form of a parallelepiped in the electric field, and further suppose that at the centre of the body the tissue is of such composition that it absorbs current selectively at some definite frequency, so that we get a concentrated heating effect at the centre, then from general physical principles, if the surrounding tissue may be supposed to be homogeneous, we have by taking three dimensional co-ordinates, as in Fig. 15.

If $x$ is the length of the body along the axis, and $h = \frac{x}{2}$, if C is the conductivity, and $\theta$ and $\theta'$ the internal and ambient temperatures respectively, then the heat flowing out of either of the faces perpendicular to

$$x = C\left(\frac{\theta' - \theta}{h}\right) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (38)$$

so that $\frac{d\theta}{dh}$ is the rate at which the temperature changes in either direction from the centre, and if we consider the $x$ axis only, this will be positive in one direction, and negative in the other, from the centre of the body. In the positive direction from the centre we have

$$-\frac{\delta}{\delta h}\left(C\frac{\delta\theta}{\delta h}\right)\delta h \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (39)$$

and in the positive direction towards the centre

$$+\frac{\delta}{\delta h}\left(C\frac{\delta\theta}{\delta h}\right)\delta h \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (40)$$

By using the convention for heat flow in the positive direction and by subtracting (40) from (39) we get

$$\left(-2\frac{\delta}{\delta h}\left(C\frac{\delta\theta}{\delta h}\right)dh\right)dy\ dz$$

$$= -\frac{\delta}{\delta h}\left(C\frac{\delta\theta}{\delta h}\right)dx\ dy\ dz \quad \ldots \quad \ldots \quad \ldots \quad (41)$$

is the rate of loss of heat at the faces perpendicular to $x$.

Similarly, by setting $g = \frac{y}{2}$ and $p = \frac{z}{2}$ we find that

$$-\frac{\delta}{\delta g}\left(C\frac{\delta\theta}{\delta g}\right) dy\, dz\, dx \qquad (42)$$

and

$$-\frac{\delta}{\delta p}\left(C\frac{\delta\theta}{\delta p}\right) dz\, dy\, dx \qquad (43)$$

is the rate of loss of heat at the $y$ and $z$ faces respectively, so that the total rate of loss of heat by the body is

$$-\left\{\frac{\delta}{\delta h}\left(C\frac{\delta\theta}{\delta h}\right) + \frac{\delta}{\delta g}\left(C\frac{\delta\theta}{\delta g}\right) + \frac{\delta}{\delta p}\left(C\frac{\delta\theta}{\delta p}\right)\right\} dx\, dy\, dz \qquad (44)$$

Now the quantity of heat the element contains is

$$S\rho T\, dx\, dy\, dz \qquad (45)$$

and the rate at which this is decreasing is

$$-S\rho\frac{\delta\theta}{\delta t}\, dx\, dy\, dz \qquad (46)$$

so that by equating (44) to (46) and cancelling out $dx\ dy\ dz$ we get

$$-S\rho\frac{\delta\theta}{\delta t} = -\left\{\frac{\delta}{\delta h}\left(C\frac{\delta\theta}{\delta h}\right) + \frac{\delta}{\delta g}\left(C\frac{\delta\theta}{\delta g}\right) + \frac{\delta}{\delta p}\left(C\frac{\delta\theta}{\delta p}\right)\right\} \qquad (47)$$

As the tissue surrounding the hot spot has been assumed to be homogeneous, C will not vary with $x$, $y$ or $z$, so C can be put outside the differentiation. We then have

$$-S\rho\frac{\delta\theta}{\delta t} = -C\left(\frac{\delta^2\theta}{\delta h^2} + \frac{\delta^2\theta}{\delta g^2} + \frac{\delta^2\theta}{\delta p^2}\right) \qquad (48)$$

$$\therefore -\frac{\delta\theta}{\delta t} = -\frac{C}{S\rho}\nabla^2\theta = D\nabla^2\theta \qquad (49)$$

where D is the diffusivity of the biological substance and $\nabla$ is the usual Laplacian operator.

If the area of the plates is larger than that of the patient's body which is presented to the high frequency field, or larger than a vessel containing an electrolytic solution under investigation, then an additional capacity in parallel with C of Fig. 13 is introduced.

We then have Z as given in equation (17a) in parallel with $Z_4 = \frac{-j}{\omega C_3}$ so that for the total impedance of the output circuit we have

$$\frac{1}{Z_5} = \frac{1}{Z} + \frac{1}{Z_4} \quad \therefore Z_5 = \frac{Z Z_4}{Z_4 + Z} \qquad (50)$$

and $\tan\theta = \frac{X}{R}$ where X is the total numerical reactance, the effect of this additional capacitative reactance will be obviously to increase the phase angle.

Considering now the effect of putting a body B of dielectric constant K in the field between the condenser plates as in Fig. 12, we have:

From the figure, by assuming that the air spaces are equal, then $x + t = d$, and if the charge per unit area of the plates when fully charged is $q$, then the intensity in the substance $= \frac{4\pi q}{K}$, so that the difference of potential between the plates

$$= 4\pi q \frac{x}{2} + \frac{4\pi q t}{K} + 4\pi q \frac{x}{2}$$

$$= 4\pi q \left( \frac{x}{2} + \frac{t}{K} + \frac{x}{2} \right) = 4\pi q \left( d - \left( 1 - \frac{1}{K} \right) t \right)$$

and if A is the area of the one side of one plate, then the capacity

$$= \frac{A}{4\pi \left\{ d - \left( 1 - \frac{1}{K} \right) t \right\}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (51)$$

K for air is unity, so that by division

$$\frac{C}{C_a} = \frac{\frac{KA}{4\pi t}}{\frac{A}{4\pi x}} = \frac{Kx}{t} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (52)$$

Thus by introducing a dielectric of thickness $t$ in the field, the value of the denominator within the bracket in equation (51) is reduced by $\left( 1 - \frac{1}{K} \right) t$ which increases the value of the condenser to the same degree as would be done by moving the plates closer together by this amount.

The shape of the body placed in the field will naturally vary according to what part of the patient's body is being treated, so that it is almost impossible to predict accurately the temperature to which the body will be raised in a field of given strength over a period of time.

There will be an optimum ratio of $\frac{x}{t}$ for a given set of conditions, which will, of course, also depend upon the internal characteristics of the ultra high frequency generator, unless the patient's circuit is independently tuned and fed by a feeder system from the generator, and the ratio will also depend upon any insulating material, other than air, which may fill or partially fill the spaces $\frac{x}{2}$.

**The Variation of Specific Heats of Matter.**

It is well known that when a substance changes its state from a solid to a liquid, or from a liquid to a gas, the specific heat may change considerably.

Furthermore, according to the Law of Dulong and Petit we have:

$$\text{Atomic weight} \times \text{specific heat} = \text{a constant.}$$

This implies that if the weight of each element is equal in grams to the number expressing the atomic weight, and therefore on the atomic theory containing the same number of atoms, the capacity for heat is the same.

And according to the same investigators the specific heat at constant volume

$$C_v = \frac{dE}{dT} = 3R = 5.9 \text{ Calories per degree C}$$

where R is the universal gas constant $= 8.315 \times 10^7$ ergs per degree gram molecule.

However, modern physical theory and experiments tend to prove that this is true for high temperatures only.

The modern theory can be only very briefly outlined as it involves the work of Bohr, De Broglie, Einstein, Schrödinger, Heisenberg, Born and Jordan, Dirac, Fermi, Debye, and Planck's Quantum Mechanics.

We will confine our brief consideration to the quantum laws and the structure of atoms and molecules, and we will suppose that the most universal laws of matter are manifested in phenomena which are independent of the particular substance with which we are dealing.

An harmonic oscillator may be conceived to be the simplest model of an atom absorbing or emitting light, and an electron may similarly be imagined to be a moving particle controlled by the action of quasi-elastic forces about a positive charge of electricity of the same magnitude as the electron, namely, $4.77 \times 10^{-10}$ E.S.U.'s, so that we have the dipole referred to in equation (6) of the article.

On the basis of Maxwell's equations, Planck has calculated the excitation of this atomic model by an external electromagnetic wave.

He found that the mean energy $\overline{W}$ of a system of such resonators of frequency $\nu$ is proportional to the mean density of radiation $\rho\nu$, a factor of proportionality depending on $\nu$ but not on the temperature T.

The equation is
$$\rho\nu = \frac{8\pi\nu^2\overline{W}}{C^2} \quad \ldots \ldots \ldots \ldots \quad (53)$$
and from the laws of statistical mechanics the mean energy of the resonators can be determined so that W, the total energy, equals the kinetic energy plus the potential energy
$$W = \frac{m}{2}\dot{q}^2 + \frac{F}{2}q^2 = \frac{1}{2m}p^2 + \frac{F}{2}q^2 \quad \ldots \ldots \ldots \quad (54)$$
$q$ is the displacement of a linear oscillator, $q$F the restoring force, and F is connected with the angular frequency $\omega$ and the frequency $\nu$ by the equation $\frac{F}{m} = \omega^2 = (2\pi\nu)^2$, and $p = m\dot{q}$ is the momentum.

In order to determine the mean value of a factor which depends upon $p$ and $q$, the factor must be multiplied by an integrating, or weighting factor, of the form $e^{-BW} = \frac{1}{kT}$ and we must take the average of this over the whole field of possible phases, this leads to
$$\rho\nu = \frac{8\pi\nu^2}{C^3} \times kT \quad \ldots \ldots \ldots \ldots \quad (55)$$
for the density of radiation, and is known as the Rayleigh-Jeans formula; but if this is integrated from 0 to $\infty$ we get
$$\int_0^\infty \rho\nu d\nu \quad \ldots \ldots \ldots \ldots \ldots \quad (56)$$
which is infinite, and which suggests that the total energy of radiation is infinite.

Thus Wien deduced another formula for the decrease of intensity of radiation at high frequencies.

$$E_\nu = \frac{8\pi\nu^3 h}{C^3} \times \frac{-h\nu}{e^{k\theta}} \quad \ldots \quad (57)$$

C is the velocity of light. But this formula is true only for low temperatures, and later Planck developed the following formula which includes both the foregoing deductions :

$$\rho\nu = \frac{8\pi\nu^2}{C^3} \times \frac{h\nu}{e^{\frac{h\nu}{kT}} - 1} \quad \ldots \quad (58)$$

$k$ is Boltzmann's constant $\left(\frac{R}{N}\right) = 1.372 \times 10^{-16}$ ergs per degree C, and $h$ is Planck's fundamental constant upon which the Quantum Theory is built up.

The value of $h = 6.54 \times 10^{-27}$ ergs per sec. So that by comparing this with equations (58) and (53) we see that the mean energy $\overline{W}$ of the resonators

$$= \frac{h\nu}{e^{\frac{h\nu}{kT}} - 1} \quad \ldots \quad (59)$$

The derivation of this formula is too long a process to enter into here as the arguments of the classical mechanics must be abandoned. But, in plain language, it means that the energy of an oscillator does not vary continuously, but that it changes in multiples of a unit $W_o$ of energy.

In statistical mechanics G is known as the partition function and is equal to $\iint e^{-BW}\,dp\,dq$, but according to Planck

$$G = \sum_{n=o}^{\infty} e^{\frac{-nW_o}{kT}} \quad \ldots \quad (60)$$

This is a geometrical series, the sum of which is

$$G = \frac{1}{1 - e^{-\frac{W_o}{kT}}} \quad \ldots \quad (61)$$

so that

$$W = \frac{\delta}{\delta\beta} \log (1 - e^{-BW_o}) = \frac{W_o e^{-BW_o}}{1 - e^{-BW_o}} \quad \ldots \quad (62)$$

therefore we have

$$W = \frac{W_o}{e^{\frac{W_o}{kT}} - 1} \quad \ldots \quad (63)$$

by putting $W_o = h\nu$ we have Planck's formula in equation (58).

We have seen that according to Wien's law given in equation (57) that the radiation depends upon the frequency and temperature, so that for the energy of the resonator we have

$$\overline{W} = \nu F\left(\frac{\nu}{T}\right) \quad \ldots \quad (64)$$

or $\overline{W}$ is a function of $\left(\frac{\nu}{T}\right)$

In the simplest model of a solid elementary substance consisting of N atoms we may assume that these atoms may oscillate in the three directions of space so that we have 3N linear oscillators, and the component of the oscillation in any direction will be proportional to the direction cosine.

From the equation $\overline{W} = \frac{1}{\beta} = kT$ we can deduce that $E = 3NkT$ and for a gram molecule $Nk = R$, where R is the absolute gas constant already given. But experiment has proved that equation (55) is true for the region of the infra red, or high temperatures only.

Thus Einstein, by making use of Planck's formula

$$\overline{W} = \frac{h\nu}{e^{\frac{h\nu}{kT}} - 1} \qquad \ldots \quad (65)$$

has deduced that the energy E for one gram molecule

$$= \frac{3RT \frac{h\nu}{kT}}{e^{\frac{h\nu}{kT}} - 1} \qquad \ldots \quad (66)$$

Debye's Theory of Specific Heats appears to have found general acceptance and it is experimentally confirmed.

To refer to this very briefly, we have

$$\frac{1}{3}\overline{C^2} = N R_o \theta \qquad \ldots \quad (67)$$

where C is the mean velocity of the molecule of a monatomic gas, N is the number of atoms in unit mass of this substance, $R_o$ the gas constant, and $\theta$ the temperature is 273.1. Thus the mean kinetic energy of a molecule

$$\tfrac{1}{2} m \overline{C^2} = \frac{3}{2} R_o \theta \qquad \ldots \quad (68)$$

as $Nm = 1$.

Considering now a solid element of N atoms per unit mass, $m$ being the mass of an atom, as before each atom having three degrees of freedom, the mean energy is the same as a monatomic gas, and is half kinetic and half potential.

Therefore, the total mean energy of an atom in solid substance $= 3 R_o \theta$, which makes the atomic heat $= 3 R_o$ or about six calories. If now $a$ is the atomic weight, $m_h$ the mass of an hydrogen atom, and E the energy of unit mass of the solid, we get

$$aE = \frac{3m}{m_h} N R_o \theta = \frac{3 R_o \theta}{m_h}$$

$$aC_v = \frac{a}{J}\frac{dE}{d\theta} = \frac{3R_o}{m_h J} \qquad \ldots \quad (69)$$

By making use of Planck's Quantum Theory, Debye has calculated that the total energy E is given as follows :

$$E = 4\pi v \left(\frac{1}{V_1{}^3} + \frac{2}{V_2{}^3}\right) \int_0^{\nu_m} \frac{h\nu}{e^{h\nu/R_o\theta} - 1} \nu^2 d\nu \qquad \ldots \quad (69A)$$

Where $V_1$ and $V_2$ are the velocities respectively of propagation of transverse and longitudinal waves. The number of modes of vibration possible whose frequencies lie in the range of $\nu$ and $\delta\nu$ is given as

$$4\pi v\nu^2\left(\frac{1}{V_1{}^3}+\frac{2}{V_2{}^3}\right)d\nu$$

$v$ is the volume of unit mass of the solid.

This equation reduces to

$$=\frac{9Nh}{\nu_m{}^3}\int_0^{\nu_m}\frac{\nu^3 d\nu}{e^{\frac{h\nu}{R_0\theta}}-1} \quad \ldots \quad (70)$$

and as $e$ must be a pure number $\frac{h\nu}{R_0}$ must be dimensions relating to temperature. Thus if we set

$$\frac{h\nu}{R_0}=\theta',\ \frac{h\nu_m}{R_0}=\theta_m$$

the integral can, by transformation be written

$$E=\frac{9NR_0}{\theta_m{}^3}\int_0^{\theta_m}\frac{\theta'^3 d\theta'}{e^{\frac{\theta'}{\theta}}-1} \quad \ldots \quad (71)$$

If now $\theta >> \theta_m$, $e^{\frac{\theta'}{\theta}}-1=\frac{\theta'}{\theta}$, and E reduces to $3NR_0\theta$ as before.

The above integral appears to be impossible to integrate in finite terms, but it appears to be of the form

$$\frac{dE}{d\theta}=3NR_0 f\left(\frac{\theta_m}{\theta}\right) \quad \ldots \quad (72)$$

$f\left(\frac{\theta_m}{\theta}\right)$ is zero for $\theta = 0$, and $\longrightarrow$ 1 for large values of $\theta$ so that we then have the formula for specific heat thus:

$$C_v=\frac{1}{J}\frac{dE}{d\theta}=\frac{3NR_0}{J}f\left(\frac{\theta_m}{\theta}\right) \quad \ldots \quad (73)$$

and

$$aC_v=5{\cdot}96\times f\left(\frac{\theta_m}{\theta}\right) \quad \ldots \quad (74)$$

J is Joule's equivalent.

$\theta_m$ will, of course, be different for different elements.

Fermi, whose theoretical work has lately been engaging the attention of physicists, and who has transferred Pauli's principle to statistics, has founded a new gas theory on the assumption that not more than a single molecule, which has been predetermined by quantum numbers, could occur.

From Fermi's statistics it appears that specific heats vanish at absolute zero temperature, and that a condition of zero energy and pressure exists.

By using Fermi's statistics Sommerfeld has shown that Fermi's Theory is particularly useful in its application to free electrons in metallic bodies, as electrons represent a completely degraded gas at ordinary temperatures on account of their small mass.

This also explains the theory that free electrons make very little contribution to the specific heat of metals.

According to Fermi, for the specific heat at constant volume we have :

$$C_v = \frac{2^{4/3}\pi^{8/3} m k^2 T}{3^{2/3} h^2 N^{2/3}} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (75)$$

Instead of Einstein's theory Fermi uses the expression

$$\frac{1}{A^{\epsilon/kT} + 1}$$

where A is a constant and $\epsilon$ is the energy with a cell containing light quanta, and $k$ as before is Bollzmann's constant.

It appears from experiments already made by many physico-therapeutists that these ultra short waves have a specific effect on colloidal substances ; also, that they penetrate much deeper than long waves.

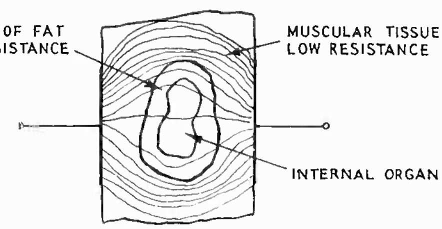



FIG. 16.

In Fig. 16 we have an idea of the distribution of an electric field within a region of the body wherein an internal organ may be located, but the composition of the organ is such that its electrical characteristics are not favourable to the absorption of current at the frequency at which the generator is working.

By altering the frequency slightly, the field distribution within the body may change to that indicated in Fig. 3 (K), where the internal organ now absorbs current, so that it is now heated more than the surrounding tissue.

It would appear, therefore, that ultra high frequency currents offer a means of raising the temperature of organs, or regions of the body, selectively ; so that at specific frequencies it may be possible to select organs for treatment without unduly influencing neighbouring organs or tissues.

Selective thermal action has also been observed, and also that the heating effect is localised within the body ; so that owing to the factors already discussed the flow of heat is outwards from within.

Therefore, owing to these effects, and the intermediate position of these ultra short waves in the spectrum between visible light waves and the longer electromagnetic waves used in wireless, and in ordinary diathermy, it is reasonable to assume that these ultra short waves may become of very great importance for medical purposes. However, so far very little is known about their biological effects and the specific properties of different frequencies in this ultra short wave band. This subject offers a very promising field for medical research workers.

With the object of providing intending investigators with high class apparatus suitable for this work the Marconi Company has developed an ultra high frequency generator, known as Type U.F.g.1, described in the last number of THE MARCONI REVIEW.

The working range is 2.6 to 8.5 metres, and the output is 160 watts over an optimum range of 3.5 to 5 metres.

And to meet the growing demand for high class valve apparatus suitable for the practical application of ultra short wave therapy, further development is in progress with the object of putting on the market high power sets specially designed for this purpose.

It is almost unnecessary to add that the Marconi Company has been intimately associated with high and ultra high frequency practice during the whole course of wireless development, so that with our long experience and research and manufacturing resources we are in a position to design and manufacture reliable apparatus for medical purposes.

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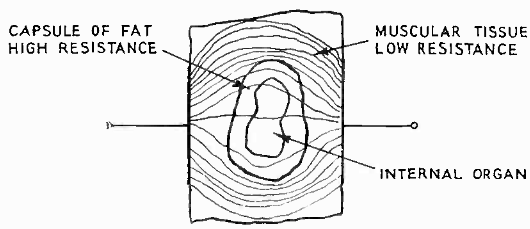


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# AN INVESTIGATION OF THE OPTICAL EFFECTS IN ELECTRICALLY STRESSED QUARTZ

*Quartz, cut in a predetermined manner, is electrically stressed and the optical effects exhibited by particular modifications in the birefringence are observed. The complicated state of vibration of the two components within the crystal is given special attention. To this end, the hypothesis of Gouy is developed and the separate activity of the linear and the circular retardation is studied. The piezo-optical constant is determined for all directions in the plane containing optic and mechanical axes. The relation between the piezo-electric and the piezo-optical constant is given. The photo-elastic constant is also brought in and the possibility of employing the piezo-optical effect commercially is discussed.*

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**Introductory Remarks.**

THE discovery of the Kerr Effect excited great interest in Europe. Some had already attempted to discover an optical effect which might be brought about by the application of electrostatic field to a dielectric, so that the first reaction to Kerr's discovery was the opinion that it was spurious. But the second reaction was more constructive ; it was the attempt to find other dielectrics than those already enumerated and experimented on by Kerr, which were susceptible to the influence of the electrostatic field.

Roentgen in 1882 repeated Kerr's identical experiment, inasmuch as he prepared quartz parallelopipeds, bored them from opposite faces so that the holes were coaxial and their extremities were separated by 0.2 cms. of the dielectric. Then he introduced metal wires into the holes and took observations with light passing between and normal to the axes of the borings. The light passing through the quartz was plane polarised and analysed after emerging from the quartz. Roentgen then tabulated his results as to the positive or negative effect of the field in the same manner as Kerr.

Later in the same year Kundt examined the effect in a novel manner. He allowed highly convergent light to pass through the specimen and observed the modification of the isochromatic system on the application of the field. This method was far more informative and its detailed description will be relegated to the section dealing with our present experiments, as we employ the same. The deformation of the isochromatic lines in the case of mechanically compressed quartz was already known before Kundt's original researches. It is not surprising, therefore, that this author compared the application of the electrostatic field with the effects of mechanical pressure ; in particular as the quartz was known to be piezo-electric. Although the results of the above author were purely qualitative, he at least was the first to establish the fact that when uniaxial quartz is electrically stressed it becomes biaxial in character. This fact was later further confirmed by Czermak, Pockels and others. Hitherto the Kerr effect in liquids and solids was regarded as being identical and it was assumed that actual deformation of the molecule would account for it in both cases. To-day it is known that the electro-optical effect in liquids is due to orientation of dipole moments and the recent researches of Debye and others have shown that as such the effect in liquids is totally different from the electro-optical effect in solids.

For quantitative results we turn later to the researches of Ny Tsi Ze.

**Effects of Mechanical Stress in Quartz.**

It will facilitate our argument considerably if we pause to examine the configuration of the ray surface of quartz when mechanical pressure is applied.

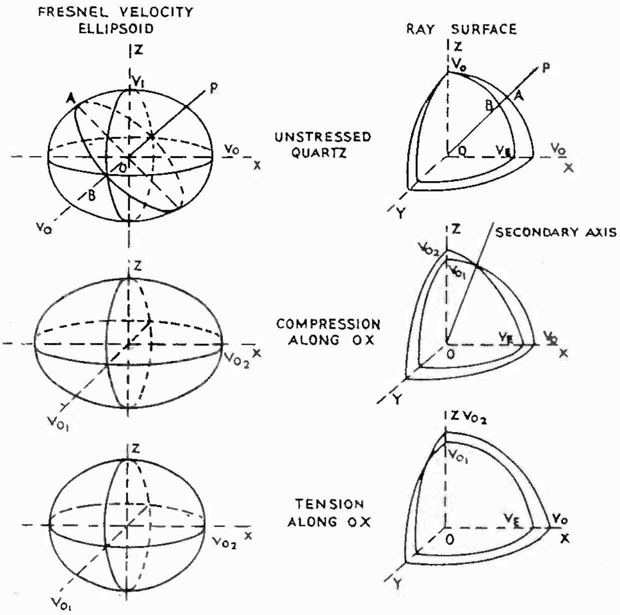



FIG. 1.

From the ellipsoid of elasticity we obtain the ellipsoid of velocity—the Fresnel ellipsoid. To determine the velocity of the two components of light travelling in any direction OP we draw a plane through the origin normal to OP. The intersection of the ellipsoid with this plane will be an ellipse, the major and minor axes of which represent to scale the velocities of the two components. Thus in our case for the direction OP we have two rays travelling with velocities OA and OB respectively. Now quartz is a positive uniaxial crystal, so that, neglecting for a moment its rotary power, taking OZ as the optic axis, the intersection of the plane YOX with the ellipsoid will be a circle. The major and minor axes will be equal; they represent the ordinary velocity $V_O$. For light travelling normal to the optic axis along OY, our normal plane will lie in that of the paper and the major and minor axes of the ellipse of intersection will be $V_O$ and $V_E$ respectively. Note that $V_O > V_E$, which, by definition, renders the crystal positive.

From the Fresnel ellipsoid we develop the ray surface, i.e., the continuous locus of all points possessing the same phase. Or, the continuous locus of all points reached in a given time by all rays setting out from the origin O at a given instant. To construct this surface take any arbitrary direction OP and mark off along it the lengths of the major and minor axes of the intersecting ellipse. Thus A and B are points on the ray surface. In our case OB will always be constant and equal to $V_O$; OA will vary between $V_O$ and $V_E$. OB therefore traces out the spherical surface of the ordinary ray and OA will trace out the surface of the extraordinary ray which will be that of a prolate spheroid. (Fig. 1.)

When pressure is applied in the OX direction the elasticity for this direction becomes greater because the material becomes denser. Consequently, the prolate spheroid of velocity becomes a triaxial ellipsoid. When the ray surface is developed from this it will be seen that the intersection of the two surfaces does not now take place along the optic axis. For compression, the new secondary—i.e., axis of single ray velocity—optic axis lies in the plane normal to the direction of the compression. For tension the secondary optic axis is coplanar with the direction of tension.

Although this gives a preliminary visual impression of the optical transformation of the medium when stressed, we have as yet considered only the case in which the two components are linearly polarised within the medium. Unfortunately with quartz matters are far more complicated, because of the rotary power introduced. Here the two components are elliptically polarised, the two extreme cases being when light travels along the optic axis and when light travels normally to this axis. In the first example, the components are circularly polarised and the two components rotate in opposite directions; in the second example the components are linearly polarised, and are at right angles to each other. We shall show later how it is possible analytically to reconcile the two effects.

**The Researches of Ny Tsi Ze.**

This investigator, working in the Sorbonne Laboratory of Prof. Fabry, was the first to obtain quantitative results as to the birefringence engendered in quartz by an electric field. Mention of his original work is therefore justifiable here. His method was to polarise the light with a nicol, and to allow the light to travel through the details of the Fabry interferometer. This meant that when the incident light was polarised in the principal plane, the interference rings were formed by the ordinary ray. When, however, the light was polarised perpendicular to the principal plane, the interference rings were due to the extraordinary ray. The diameter of the first and innermost ring changed when the polariser was oriented through a right-angle. By observing the modification of this diameter it was possible to determine the difference in refractive index between both rays. It was also possible to obtain the refractive index for each ray. These observations were made for light travelling in the direction of the electric axis. In order to determine the refractive index for the remaining ray he made observations with light travelling along the mechanical axis. This time he employed two specimens so that the resultant retardation before stressing was small. Hence when the light, having passed through the polariscope with crossed nicols, entered a spectroscope dark interference bands could be seen. Upon applying the electric field, these bands began to shift and the measure of this shift served to determine the birefringence, or the difference in the two refractive indices. For the three refractive indices, the modification per unit electrostatic field per unit light path was found to be

$\delta\mu_e = -1.6 \times 10^{-8}$ for ray vibrating along electric axis.
$\delta\mu_m = -3.9 \times 10^{-8}$ ,, ,, ,, mechanical axis.
$\delta\mu_o = -2.9 \times 10^{-8}$ ,, ,, ,, optic axis.

Hence the birefringence along the optic axis is

$$\delta\mu_m - \delta\mu_e = 2.3 \times 10^{-8}$$

the birefringence along the mechanical axis is

$$\delta\mu_o - \delta\mu_e = 1.3 \times 10^{-8}$$

and the birefringence along the electric axis is

$$\delta\mu_m - \delta\mu_o = 1.0 \times 10^{-8}$$

We shall term these birefringences the piezo-optical constant.

**Airy's Hypothesis.**

Whatever the form of light vibration incident on the face of the crystal, the vibration within the crystal is of a different nature if the crystal is anisotropic or active. For light travelling normally to the optic axis in quartz, the vibrations within the crystal are supposed linearly polarised and vibrating in mutually perpendicular directions. There is one vibration direction in a plane which contains also the optic axis and the direction of light travel. This plane is the principal plane. In our analysis, OX will be the trace of the principal plane on that of the drawing.

Light travelling along the optic axis of quartz does not split up into two linearly polarised components. The two components in this case are circular, which rotate in opposed directions. They were separated by Fresnel. The resulting rotation of the plane of polarisation is due to phase difference set up between the two circular components. For a rotation $\rho$ of the plane of polarisation the phase difference is $\omega$.

But $$\rho = \frac{\omega}{2}$$

These quantities are in circular measure. In order to facilitate the reading of the analysis angles will be expressed in Greek letters and phase differences as fractions in small English type. The above expression would then read

$$\gamma = \pi w$$

When light travels at a small angle to the optic axis, the components are neither linearly nor circularly polarised. They are elliptically polarised and the component ellipses are conjugate. The ratio of their axes are the same, and it is generally denoted by $k$. As in the case of the circular components, the elliptical components vibrate in opposed directions. If one is right-handed, the other is left-handed. Take, for instance, a linear vibration along OX of the form

$$x = a \sin wt$$

then to resolve this linear vibration into two elliptical components whose axes are parallel and perpendicular to the initial vibration and whose axial ratio is $k$ we write

$$\left.\begin{aligned} x &= ak \sin wt \\ y &= a \cos wt \end{aligned}\right\} \text{ left-handed.}$$

$$\left.\begin{aligned} x &= \frac{a}{k} \sin wt \\ y &= -a \cos wt \end{aligned}\right\} \text{ right-handed.}$$

The supposition that the components were elliptical is due to Airy. He considered that on emergence from the crystal one of these components suffered a phase change with respect to its companion. If $\alpha$ is the phase advance of one and $\beta$ is that of the other, then the emerging vibration will be of the form

$$\left.\begin{aligned} x &= ak \sin (wt+\alpha) \\ y &= a \cos (wt+\alpha) \end{aligned}\right\}$$

$$\left.\begin{aligned} x &= \frac{a}{k} \sin (wt+\beta) \\ y &= -a \cos (wt+\beta \end{aligned}\right\}$$

The resulting angular phase difference will be

$$\delta = \alpha - \beta \quad \ldots \quad (1)$$

And the fractional phase difference will be

$$d = a - b \quad \ldots \quad (2)$$

It can be shown that if $k = \tan \epsilon$, and if $\omega$ is the phase advance of one component on the other, then the rotation of the plane of polarisation is given by the expression

$$\tan \rho = \sin 2 \epsilon \tan \frac{\omega}{2}$$

If the light travels along the optic axis, then $k$ is unity and

$$\rho = \frac{\omega}{2}$$

**Gouy's Hypothesis.**

For the case of light travelling in quartz normal to the optic axis we have within the quartz the two components

$$\begin{aligned} x &= a \sin wt \\ y &= b \sin wt \end{aligned}$$

On emergence from the crystal one component will have advanced in phase, and the resulting elliptical vibration will be

$$\begin{aligned} x &= a \sin wt \\ y &= b \sin (wt+\delta) \end{aligned}$$

having the form

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} - 2 \frac{xy}{ab} \cos \delta = \sin^2 \frac{\delta}{2}$$

and whose major axis is inclined $\theta$ to the OX vibration direction of the quartz. (See Fig. 2.) Referring this ellipse to its own axes as co-ordinates we have

$$\begin{aligned} \zeta &= a \cos \theta \sin wt + b \sin \theta \sin (wt + \delta) = A \sin (wt + \alpha) \\ \eta &= -a \sin \theta \sin wt + b \cos \theta \sin (wt + \delta) = B \sin (wt + \beta) \end{aligned} \quad \ldots \quad (1)$$

giving

$$\begin{aligned} A^2 &= a^2 \cos^2 \theta + b^2 \sin^2 \theta + ab \sin 2 \theta \cos \delta \\ B^2 &= a^2 \sin^2 \theta + b^2 \cos^2 \theta - ab \sin 2 \theta \cos \delta \end{aligned}$$

so that we find

$$A^2 + B^2 = a^2 + b^2 \quad \ldots \quad (2)$$

and

$$A^2 - B^2 = (a^2 - b^2) \cos 2 \theta + 2 ab \sin 2 \theta \cos \delta$$

Now as the ellipse is referred to its own axes as co-ordinates the value of $A^2 - B^2$ will be a maximum. Differentiating the above expression and equating to zero we derive the well-known relation

$$\tan 2\theta = 2 \frac{ab}{a^2 - b^2} \cos \delta \quad \ldots \quad (3)$$

and putting $\frac{b}{a} = \tan i$ we obtain

$$\tan 2\theta = \tan 2i \cos \delta \quad \ldots \quad (4)$$

If in equation 1 we equate the coefficients of sin $wt$ and cos $wt$ we find

$$A \cos \alpha = a \cos \theta + b \sin \theta \cos \delta$$
$$A \sin \alpha = - b \sin \theta \sin \delta$$
$$B \cos \alpha = - a \sin \theta + b \cos \theta \cos \delta$$
$$B \sin \alpha = - b \cos \theta \sin \delta$$

from which follows

$$AB \sin (\alpha - \beta) = ab \sin \delta$$

But, however, as the vibration is referred to the axes of the ellipse, then the angles $(\alpha - \beta)$ must be equal to $\pm \frac{\pi}{2}$ so that the above reduces to

$$AB = ab \sin \delta \quad \ldots \quad (5)$$

putting $\frac{B}{A} = \tan I$ we find by trigonometry

$$\sin 2I = \frac{2\,AB}{A^2 + B^2}$$

and thus

$$\sin 2I = \frac{2\,ab}{a^2 + b^2} \sin \delta = \sin 2i \sin \delta \quad \ldots \quad (6)$$

from 2 and 5.

Similarly we can establish the relations

$$\tan 2i = \tan 2I / \sin \delta \cos 2\theta \quad \ldots \quad (7A)$$
$$\cos 2i = \cos 2I \cos 2\theta \quad \ldots \quad (7B)$$
$$\tan \delta = \tan 2I / \sin 2\theta \quad \ldots \quad (7C)$$

In what follows we shall put $\upsilon$ equal to the total angular phase difference and let $\delta$ equal the phase difference between the component. In this case $\upsilon = \delta$, but we shall see that this is not always true when we have to consider conjugate elliptical components.

The simplest case we can take for example is that of pure rotation. Here we have the phase difference $\omega$ between the circular components equal to twice the phase difference $\rho$ of the emergent ray.

Equation 4 gives us the relation between the rotation of the axes of the ellipse and the phase difference and equation 6 gives the relation between the ratio of the ellipse and the phase difference. In order to obtain this relationship to the specific phase difference, we must differentiate both equations with respect to the thickness $l$ of the crystal. The specific phase difference is here a measure of the fractional phase difference per unit length of specimen. This phase difference is engendered by linear retardation alone.

We find, then, from equation 4

$$2\frac{d\theta}{dl} = (\tan 2i \cos^2 2\theta \sin \upsilon)\, p \qquad \ldots \qquad (8)$$

and from equation 6

$$2\frac{dI}{dl} = \left(\frac{\sin 2i}{\sin 2I} \cos \upsilon\right) p \qquad \ldots \qquad (9)$$

in which $p = \dfrac{d\left(\frac{\upsilon}{2\pi}\right)}{dl}$ is the specific phase difference.

We have thus shown that when light passes through the quartz specimen the retardation which it suffers in doing so may be expressed as the results of two simultaneous effects. One is a pure rotation of the axes and the other is a modification of the ratio of the axes.

For light travelling parallel to the optic axis of the crystal, rotation only takes place, so that here

$$\frac{dk}{dl} = 0$$

and when this is the case we note from 9 that $\cos \beta = 0$, therefore $\sin \beta = 1$. Then substituting for tan $2i$ from 7A, we have

$$2\frac{d\theta}{dl} = \tan 2I\, p$$

and putting

$$\tan I = k$$

we find

$$\frac{d\theta}{dl} = \frac{k}{k^2-1}\, p$$

but $\dfrac{d\theta}{dl} = r = \dfrac{w}{2}$, the fractional rotation which we know from section 4 to be equal to half the fractional phase advance, hence we have

$$\frac{w}{2} = \frac{k}{k^2-1}\, p \qquad \ldots \qquad (10)$$

which gives us the relations between linear and circular retardation.

To ascertain the relationship between the circular retardation and the total retardation we consider the second equation of the preceding section. The total phase difference is the difference of phase existing between the two elliptical components and is

$$d = a - b$$

This takes place for an arbitrary thickness $l$ of the crystal. The form of vibration when the thickness has been increased by $dl$ will be

$$\frac{y}{x} = \left(\frac{k}{k^2+1}\, d\right) dl$$

But this is the equation of a straight line inclined an angle $\upsilon = \frac{w}{2}$ with the co-ordinate. Hence we can equate

$$\frac{k}{k^2+1}\, d\, dl = \frac{w}{2}\, dl$$

and find

$$r = \frac{w}{2} = \frac{k}{k^2+1}\, d \quad \ldots \quad (11)$$

giving the relaton between the total and the circular retardation. We can put equations 10 and 11 in the form

$$\begin{aligned} w &= p \tan 2\epsilon \\ w &= d \sin 2\epsilon \\ p &= d \cos 2\epsilon \end{aligned} \quad \ldots \quad (12)$$

Adding the squares of the circular and the linear retardation we arrive at Gouy's expression, which states that the square of the total retardation is equal to the sum of the squares of the circular and the linear retardations.

$$d^2 = w^2 + p^2 \quad \ldots \quad (13)$$

**Further Mathematical Investigation.**

We have yet to establish the relation between the inclination to the axis of the emergent elliptically polarised ray, the phase difference between the two components and the values of the constituents of the Gouy expression. In order to accomplish this we first write down the expression for the conjugate elliptical components of Airy, this time in a slightly different form to facilitate the analysis.

$$\left.\begin{aligned} x_1 &= k \sin wt \\ y_1 &= \cos wt \end{aligned}\right\}$$

$$\left.\begin{aligned} x_2 &= \frac{1}{k} \sin wt \\ y_2 &= -\cos wt \end{aligned}\right\}$$

Introducing the phase difference we have

$$\left.\begin{aligned} x_1 &= k \sin wt \\ y_1 &= \cos wt \end{aligned}\right\}$$

$$\left.\begin{aligned} x_2 &= \frac{1}{k} \sin (wt + \delta) \\ y_2 &= -\cos (wt + \delta) \end{aligned}\right\} \quad \ldots \quad (1)$$

To deduce the final vibration we resolve along the co-ordinate axes and we have

$$\begin{aligned} X &= x_1 + x_2 = a \sin (wt + \alpha) \\ Y &= y_1 + y_2 = b \sin (wt + \beta) \end{aligned} \quad \ldots \quad (2)$$

from which we find

$$a^2 = \left(k + \frac{1}{k}\right)^2 - 4 \sin^2 \frac{\delta}{2}$$

$$b^2 = 4 \sin^2 \frac{\delta}{2}$$

But as $\frac{b}{a} = \tan i$, $k = \tan \epsilon$, and putting $\upsilon = (\alpha - \beta)$

we find $$\frac{b^2}{a^2} = \tan^2 i = \frac{4\, k^2 \sin^2 \frac{\delta}{2}}{(1 + k^2)^2 - 4k^2 \sin^2 \frac{\delta}{2}}$$

which on transformation becomes

$$\tan 2i = \frac{\sin 2\epsilon \sqrt{(1 - \cos \delta)\ (2 - \sin^2 2\epsilon)\ (1 - \cos \delta)}}{\cos^2 2\epsilon + \sin^2 2\epsilon \cos \delta}$$

substituting for $\tan 2i$ from equation 4 of the preceding section we obtain

$$\tan 2\theta = \frac{\sin 2\epsilon \sin \delta}{\cos^2 2\epsilon + \sin^2 2\epsilon \cos \delta} \qquad \ldots \quad (3)$$

On further substitution from equation 12 of the last section we arrive finally at the expression

$$\tan 2\theta = \frac{wd \sin \delta}{p^2 + \omega^2 \cos \delta}$$

$$= \frac{wd \sin 2\pi d}{p^2 + w^2 \cos 2\pi d} \qquad \ldots \quad (4)$$

In equation 1, giving the elliptical components for a linearly polarised ray vibrating parallel to the OX axis, that is, horizontally, and in equation 2 giving the resultant vibration after passage through the crystal, we have means to ascertain the phase relationship in the following manner :

We have

$$\tan \alpha = \frac{\sin \delta}{k^2 + \cos \delta}$$

$$\tan \beta = \frac{\sin \delta}{1 - \cos \delta} = \cot \frac{\delta}{2}$$

If we let $\upsilon = \alpha - \beta$

then $\tan \upsilon = \tan (\alpha - \beta) = \frac{1 - k^2}{1 + k^2} \tan \frac{\delta}{2}$

or $\tan \upsilon = \cos 2\epsilon \tan \frac{\delta}{2} \qquad \ldots \quad (5)$

If we put $\frac{b}{a} = \tan i$, then in a similar manner we can deduce the expression

$$\cos i = \frac{2k}{1 + k^2} \sin \frac{\delta}{2}$$

or $$\cos i = \sin 2\epsilon \sin \frac{\delta}{2} \qquad \ldots \quad (6)$$

Transforming equations 5 and 6 we have

$$\cos \frac{\delta}{2} = \cos \upsilon \sin i$$

and $$\tan 2\epsilon = \frac{\tan 2i}{\sin \upsilon}$$

These are the two equations with which it is possible to determine the value of $k$ and the phase advance $\delta$ of the one elliptical component on the other.

The case just taken refers to the primitive ray vibrating in the horizontal direction. We can deduce in a similar manner the expression for the case in which the primitive ray vibrates in the vertical direction and also for the 45 deg. direction. Collecting all these expressions together we have—

For primitive ray vibrating horizontally

$$\cos\frac{\delta}{2} = \cos\upsilon\cos i$$

$$\tan 2\epsilon = \frac{\tan i}{\sin\upsilon} \quad \ldots \quad (7\text{A})$$

For primitive ray vibrating vertically

$$\cos\frac{\delta}{2} = \cos\upsilon\cos i$$

$$\tan 2\epsilon = \frac{1}{\sin\upsilon\tan i} \quad \ldots \quad (7\text{B})$$

For primitive ray vibrating at 45 deg.

$$\cos\delta = \cos\upsilon\sin 2i$$

$$\tan 2\epsilon = \frac{1}{\sin\upsilon\tan 2i} \quad \ldots \quad (7\text{C})$$

With the aid of equations 5 of this section, and 7B of the preceding section, we can deduce, after simplification,

$$\sin 2\mathrm{I} = \sin 4\epsilon\,\sin^2\frac{\delta}{2} \quad \ldots \quad (8)$$

which completes the list of equations we need to examine the values of the various constants and to determine them experimentally.

*(To be continued.)*

# A SINGLE STROKE TIME BASE

*The description given below refers to a method of synchronising time base operation and camera control in a cathode ray equipment and has been developed to meet certain specified requirements in particular forms of cathode ray technique.*

---

THE time base described below was specifically developed for recording amplifier noise and tape noise in magnetic recording systems and the operation entailed merely consists of throwing a single traverse across the cathode ray screen at a given time determined by the operator.

In the circuit diagram shown in Fig. 1, a condenser is connected through a constant current device to a source of constant potential. Connected directly across this condenser are two keys $C_1$ and $C_2$. When the operating button is pressed, a sequence of operations is performed in order as the key is pressed further home. Note that in the unoperative position $C_1$ is open and $C_2$ is closed.

Each operation of the key is performed in about 1/16-inch of movement of the push button, i.e., when the key is pressed 1/16-inch the first operation is performed, when this distance has increased to 1/8-inch the second operation is performed, and at 3/16-inch the last operation is performed. An operator of the equipment need not be aware of these operations, as the complete sequence is performed by pushing the button 3/16-inch, i.e., right home.

The camera shutter is connected mechanically to the push-button by means of a cable release and lever arm shown in Fig. 2.

The first operation is to close $C_1$, since $C_2$ is already closed, the condenser is short circuited and discharged. This throws the cathode ray beam off the screen.

The second operation is to open the camera shutter. As stated before, this is performed by means of the cable release.

The third operation is to open $C_2$, when the condenser is allowed to charge at a linear rate, i.e., at constant current through the screen grid valve shown in the circuit diagram.

The shutter is set to operate at about 1/5th sec., and hence closes after the third operation is completed.

Sparking at the contacts causes traces to be made on the oscillograph, and the two keys, $C_1$ and $C_2$, are used to avoid this. Sparking is present when $C_1$ is closed, but since the shutter is closed this is not important. At the instant of break of $C_2$ there is no E.M.F. across the key, hence no sparking should result. In practice, however, it is found that this condition is fulfilled only if the linear traverse time of the oscillograph is greater than 5 millisec., when 500 volts are used for supplying the circuit. This time has, however, been found adequate in many commercial applications. In any case, if a large and complicated waveform is to be examined, the writing speed of the oscillograph would be adequate at higher speeds.

Methods of suppressing the cathode ray beam have been tried, other than the use of a shutter, and it is found that the usual methods all tend to produce plate "fogging," i.e., if the Wehnelt cylinder is biassed to cut-off there is still some

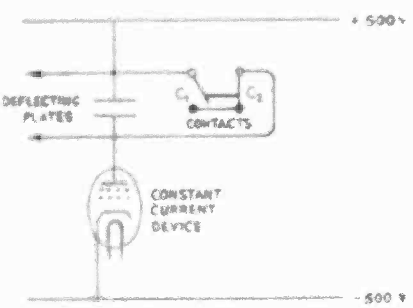



FIG. 1.

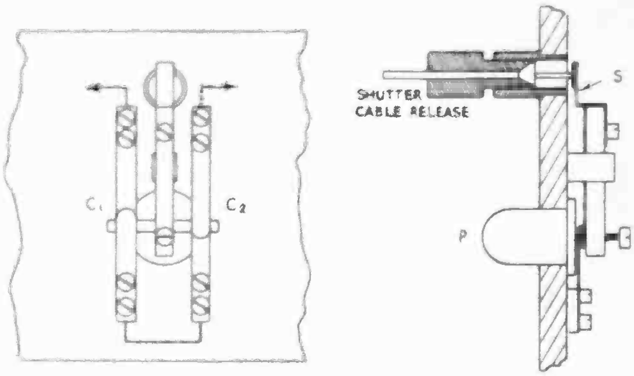



FIG. 2.

fluorescence in the tube unless the cylinder is normally at a positive potential. Alternatively, in both the Wehnelt cylinder circuit and in the anode circuit of the oscillograph, if this be interrupted the inductance and capacity of the leads, and the variation in the load on the power supply causes defects in the trace. If the Wehnelt cylinder be biassed, this is shown as a blurred image at the commencement; in the case of the anode circuit it is shown as reduced sensitivity at the beginning of the trace. These difficulties are obviously overcome by the use of a shutter as described.

If it is desired to extend the lower limit of the exposure time, thyratrons controlled by the switches may be used, and this would avoid sparking at the contacts. This method may not, however, be extended to the case of uncontrolled transients, which must operate the time base by themselves, and be recorded after delay in a suitable cable.

Tests have been made on cathode ray equipment modified to cover this improvement and some records have been made on the modified arrangement for the purpose of testing magnetic recording tape. The time base is now practically foolproof to operate.

A. J. YOUNG.

# MARCONI NEWS AND NOTES

## AUSTRIAN HONOUR FOR MARCHESE MARCONI.

MARCHESE MARCONI has been awarded the Wilhelm Exner Medal given annually by the Austrian Association of Commerce and Industry to " persons who by their scientific work have given special increase to industrial production." The Wilhelm Exner Medal is recognised as one of the major Austrian scientific distinctions, and this is the first time that it has been awarded to a non-German-speaking scientist.

Founded in 1839, the Austrian Association of Commerce and Industry is principally concerned with furthering the application of scientific advances to industry and trade, and the medal and accompanying diploma which is the Society's award of honour was instituted in memory of Dr. Wilhelm Exner, a pioneer of applied science in Austria.

**Broadcasting in India.**

THE High Commissioner for India in London has placed a contract with the Marconi Company for the supply and erection of a 20-kilowatt broadcasting station at Delhi.

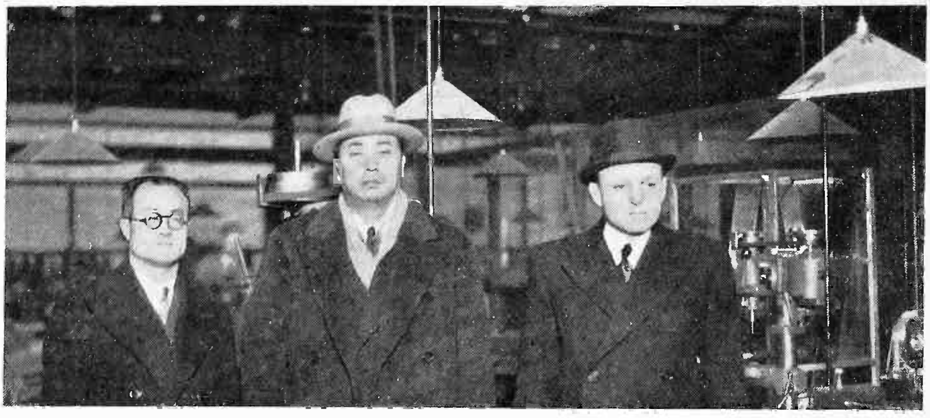
This is the first step towards the accomplishment of the Indian Government's policy of extending broadcasting in India announced by the Viceroy in August last year. Work on the manufacture of the equipment for the Delhi station is to begin immediately at the Marconi Works, Chelmsford.

The transmitter will be of advanced design, incorporating the most modern developments of broadcasting technique, and with its unmodulated aerial energy of 20 kilowatts it will be several times more powerful than any broadcasting station previously erected in India.

**Wireless Communications in China.**

RAPID progress is now being made in linking up all the principal cities and commercial centres of China with a network of wireless communications services, and the Chinese Ministry of Communications has just placed a contract with the Marconi Company for seven Type S.W.B.8 transmitting equipments for these services.

*Cardinal Pacelli, Papal Legate to the Eucharistic Congress in Argentina, broadcasting from "Radio Excelsior," Buenos Aires, which uses a Marconi 20-kilowatt transmitter.*



*His Excellency Yu-Fei-Peng, Chinese Vice-Minister of Communications (centre), and Mr. P. F. Woo (left), at the Marconi Works, Chelmsford.*

The Type S.W.B.8 equipment is a short-wave transmitter of modern design capable of an output of 3.5 kilowatts on continuous wave telegraphy and 2.6 kilowatts carrier on telephony, and among its special features is ease of wave-changing with pre-set inductances.

**A Distinguished Visitor.**

The active interest that is taken by the authorities in China in the application of modern wireless technique to that country's growing needs in the sphere of communications was also in evidence during the recent visit to England of a Commission from the Chinese Ministry of Communications, when His Excellency Yu-Fei-Peng, Vice-Minister of Communications, made a tour of inspection of the Marconi Works at Chelmsford, accompanied by Mr. P. F. Woo. His Excellency spent a whole day on this visit and expressed lively interest in all that he saw, both in regard to work in production and research and development activities.

In addition to the new Marconi S.W.B.8 stations for internal communications in China, there is already in operation the Marconi-equipped Beam station at Shanghai which provides external services between China and Europe and the United States of America. This station, where are installed two Beam transmitters and four sets of receiving apparatus, was visited by Marchese Marconi during his tour of China in 1933.

## New Aids for Air Navigation.

THE value of wireless aids to air navigation of the class independent of special ground organisation has now been so fully demonstrated by the utility of the Marconi "homing" device, both on regular air routes and on special flights, that further wireless navigational instruments of this kind are to be developed.

For this purpose the Marconi Company, who were pioneers in this class of direction finding work and in aircraft wireless communications generally, have acquired exclusive rights of two further patents of outstanding importance. These are Smith and Meredith's Radio Azimuth patent No. 357968, as developed by the Royal Aeronautical Establishment, Farnborough, and Simon's Radio Range and Direction Finder (British Application No. 32555/34 ; Radio Navigational Instrument Corporation).

In the first place the now familiar " homing " device itself will be developed to provide a visual indication where this is of advantage, particularly for example in regard to fog landing operations. In practice, the pilot of an aircraft fitted with such apparatus has only to watch a needle on a dial to know whether he is on his set course. If he deviates the movement of the needle shows immediately the direction of the deviation and also gives an approximate indication of its extent.

The Simon Radio Range and Direction Finder provides a means of giving visually the bearing of any wireless transmitting station in degrees and at the same time an approximate indication of its distance in certain circumstances. The apparatus employs two small loop antennæ, which are arranged at an angle to each other, and each connected to a separate superheterodyne receiver. Means are provided on a dashboard meter of giving simultaneous visual comparison of the relative voltages in the two loops, and the direction of the transmitting station is thus indicated.

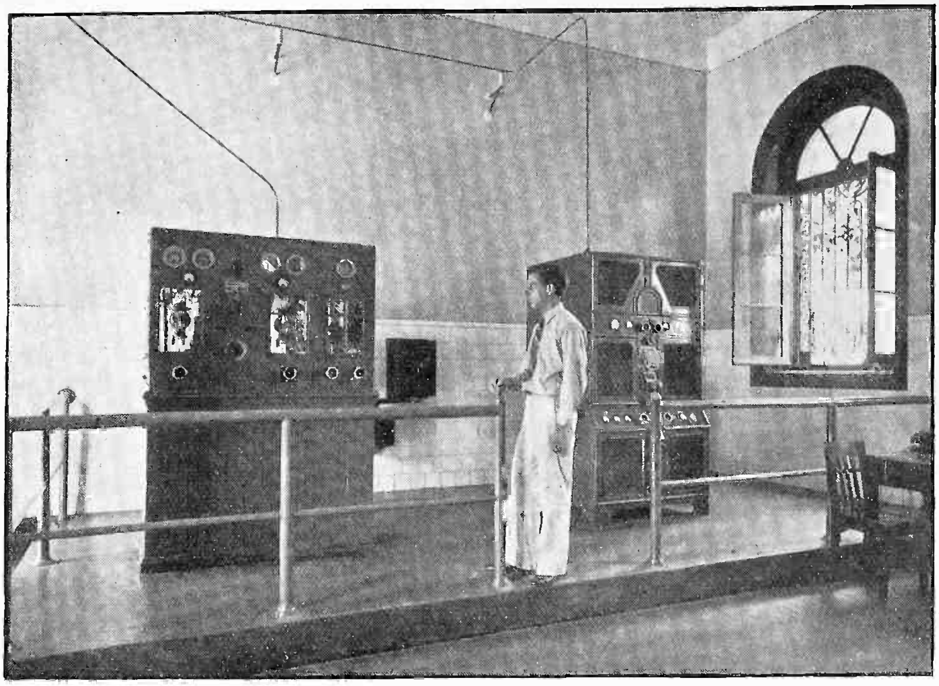
The Marconi Company are already operating under Smith and Smith's patents Nos. 299507 and 322326, which cover in detail the methods employed in the Marconi " homing " device.

**Police Wireless for Brazil.**

THE police authorities of the State of Sao Paulo, Brazil, have just placed an important contract with the Marconi Company for the supply of wireless equipment to be used for the establishment of a network of police wireless services throughout the State.

Communication is to be provided between the police headquarters in the capital and the principal police stations in the outer districts of Sao Paulo, and also with motor patrols, some of which will carry combined transmitting and receiving equipment for two-way working and others receivers only.

For the operation of these services the contract includes the supply of two powerful transmitting and receiving equipments for long distance communication on short waves, four smaller stations for provincial police centres, and six transmitters and 18 receivers for motor patrols, together with auxiliary equipment.



*Marconi transmitters Type S.250 (short-wave) and T.A.4a (medium-wave) at the Central Police Station, Rio de Janeiro.*

**Marconi-Adcock Equipment for Egyptian Aerodrome.**

A MARCONI-ADCOCK wireless direction finding equipment, Type D.F.g.10, is being installed for the Egyptian Ministry of Communications at the Mersa Matruh aerodrome near Alexandria. This aerodrome is used by Imperial Airways aircraft on the African and Indian air routes, and the new direction finder will provide additional wireless guidance over the Mediterranean crossing and over the Northern stage of the flight across Africa.

The special advantage of the Marconi-Adcock equipment for important air routes is its ability to provide a reliable 24-hour direction finding service, not being materially subject to the incalculable phenomenon of " night effect " which renders ordinary wireless direction finding systems practically useless during the hours of darkness. The same installation can also be used for normal reception on telephone and telegraph services with aircraft in flight and other aerodromes.

**Wireless for Empire Airways.**

THE new D.H.86 four-engined aircraft for the Singapore-Brisbane section of the England-Australia air route of Qantas Empire Airways Limited are fitted with Marconi combined medium and short wave transmitting and receiving equipment to enable them to maintain constant wireless contact with the ground or with ships and coast stations. They also carry the Marconi " homing " device as an aid to navigation.

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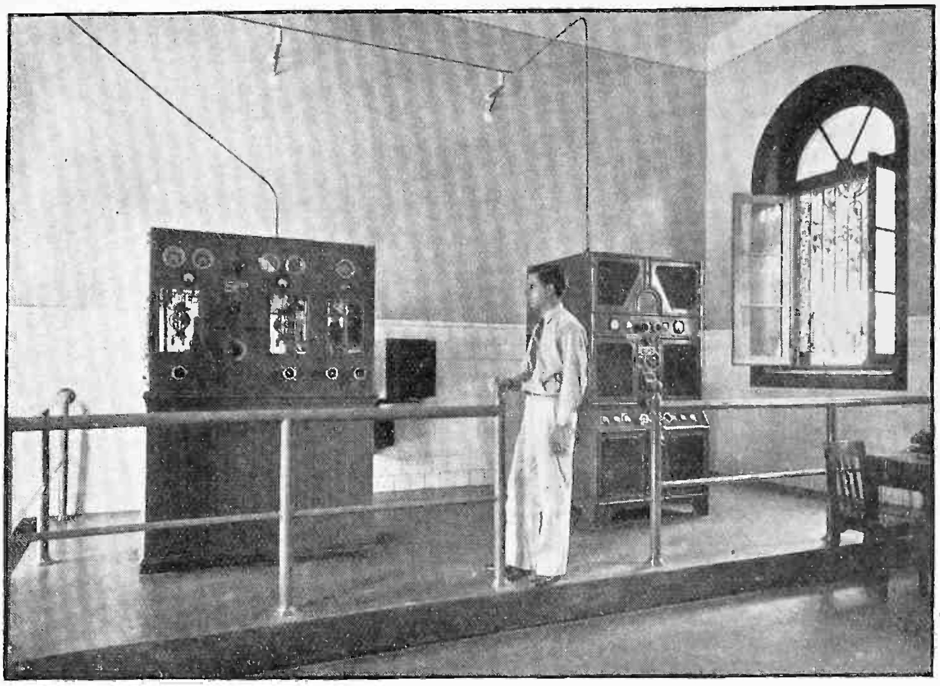

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Binders for the 1935-36 issues of the "MARCONI REVIEW" are now available at a cost of 3s. 6d. each.

Applications for Binders should be forwarded, with remittance, to

Publicity Manager, Marconi's Wireless Telegraph Co., Ltd., Electra House, Victoria Embankment, London, W.C.2.

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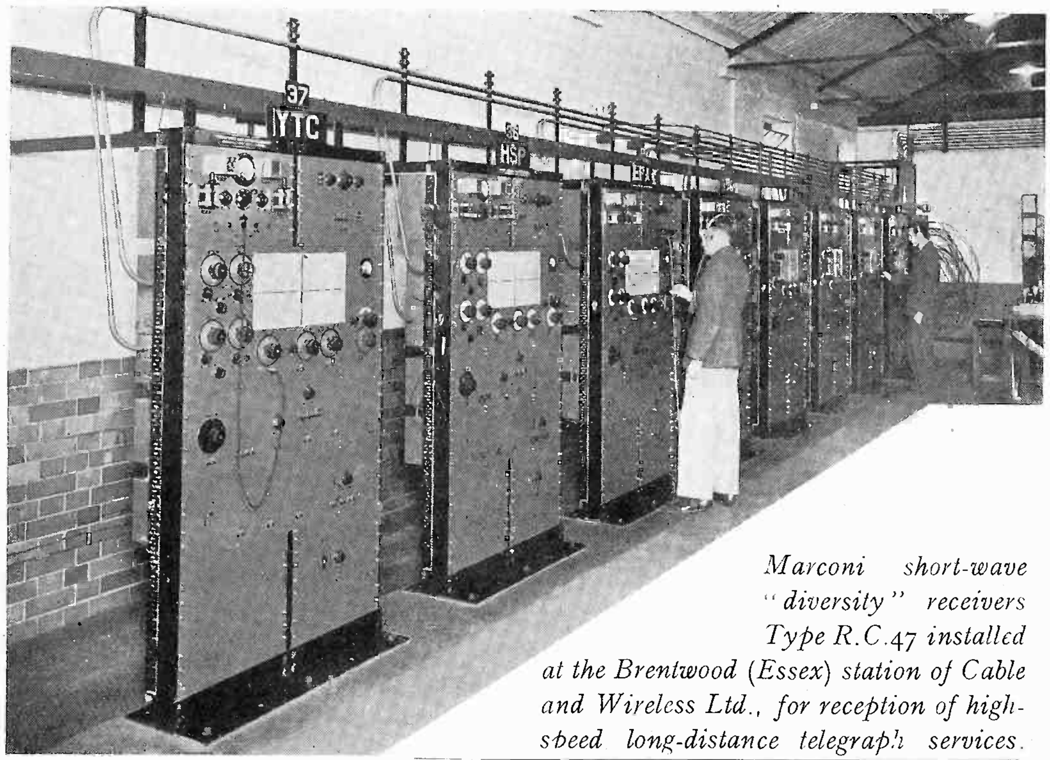
The three larger Junkers aircraft recently delivered to South African Airways are also fitted with Marconi transmitting and receiving equipment Type A.D.37/38.

These machines link up with the present London-Cape Town air route, while a number of smaller aircraft, operating internal routes, are fitted with the new Marconi medium wave sets Type A.D.41/42. All are to carry Marconi directional receivers as an aid to navigation.

The Marconi Company provided an experienced engineer and two expert operators to accompany the larger aircraft on their delivery flight from Europe to South Africa, during which excellent wireless working was attained on all machines.

On the medium waves, they gave a practically uniform performance of two-way communication over 600 miles on continuous wave telegraphy, while on short waves (with the A.D.37/38 equipments) good telegraph working was carried out with Victoria West over 1,200 miles and two-way telephony over 1,000 miles. Ranges between the machines in flight were up to 130 miles by telephony and 200 miles by telegraphy. "Homing" was also successfully used on most stages of the flight, at ranges of 100 miles on Athens, 500 miles on Almaza, 150 miles on Kisumu, 100 miles on Salisbury (Rhodesia) and 300 miles on Germiston.




*Marconi short-wave "diversity" receivers Type R.C.47 installed at the Brentwood (Essex) station of Cable and Wireless Ltd., for reception of high-speed long-distance telegraph services.*