By changing over from a single coil to a coiled coil filament in the case of argon-filled electric lamps an average improvement of 15 per cent was obtained in the efficiency of the lamps. Detailed investigations were carried out on ten different kinds of lamps specially made for the purpose on the effect of krypton instead of argon as a filling. From these investigations and from results of life tests of krypton-filled coiled coil electric lamps on the market it may be concluded that with the same life and luminous flux an improvement of about 3 per cent in the average efficiency could be obtained by changing over from argon to krypton. In connection with the cost of the krypton filling this improvement cannot be realized at once in practice.

Research during the last ten years has been especially devoted to a study of this dependence and we shall here discuss the results in turn.

The form of the filament

An important possibility of improving the efficiency of gas-filled lamps, and one which has been investigated thoroughly, relates to the form of the filament itself. Langmuir showed that the heat lost by a filament depends mainly on its length and only to a very limited extent upon its diameter, and at the same time that a coiled tungsten wire does not differ from a massive wire whose diameter is the same as that of the coil, as far as the loss of heat is concerned.

Instead of Langmuir's formula for the loss of heat the following empirical formula can very well be used:

\[ W = C \cdot l \cdot d^\delta \cdot T^\tau \]  

where

- \( W \) = the loss of heat to the gas,
- \( l \) = the length of the filament,
- \( d \) = the diameter of the filament,
- \( T \) = the absolute temperature of the filament and
- \( C \) = a constant depending on the gas mixture.

The exponents \( \delta \) and \( \tau \) are indeed again functions of the diameter and of the temperature, respectively, but they may be considered as constants within a wide range. It is found that the experimental values are best matched by choosing:

\[ \delta = 0.3. \]

A large number of measurements which have been carried out during the last 15 years have confirmed this value of \( \delta \). At the temperatures mentioned in this article of 2500 to 3000 °K, \( \tau \) is about 1.6.

1) I. Langmuir, Phys. Rev., 34, 401, 1912;
2) Cf. for example: W. Geiss, Philips techn. Rev., 1, 97, 1936.

For a given gas and for the temperature $T$, therefore, the ratio of conduction losses for two filament's of the dimensions $l_1 d_1$ and $l_2 d_2$ is

$$W_1 : W_2 = l_1 d_1^3 : l_2 d_2^3.$$  

If by means of a different form of filament it is desired to reduce the loss of heat to one half of that of an ordinary coil, the following relation must hold:

$$2l_2 \cdot d_2^{0.3} = l_1 \cdot d_1^{0.3}.$$  

This means practically that the new filament must be slightly less than half as long as the first filament, but that it may be much thicker.

The rate of evaporation in a gas atmosphere

In addition to the form of the filament, its rate of evaporation in a gas atmosphere is very important for the efficiency of a lamp. The total radiation of a filament and the luminous flux are functions of the temperature. For their ratio $E$, namely the luminous flux divided by the energy radiated per second, in not too large a temperature region the following formula is sufficiently accurate:

$$E = aT^3.$$  


On the basis of the last article it can be shown, that the calculation of the heat losses according to Langmuir's formula agrees well with the measured values both for the single and the coiled coils.
In the same way for the rate of evaporation \( v \) of the filament:

\[
v = \gamma T^{\delta}.
\]

(3)

In these expressions \( a, f \) and \( g \) are material constants of the filament, while for a given form of the filament \( \gamma \) depends upon the nature and the pressure of the gas surrounding the filament. This constant will be smaller the more the gas atmosphere opposes the diffusion of the vapourized molecules of the filament. Therefore, for a given filament one may speak of a diffusion constant \( \gamma \) of the metal in the gas with which the lamp is filled.

If one starts with the experimentally confirmed assumption that a filament has reached the end of its life when a certain part of its weight has been evaporated, its life is inversely proportional to the rate of evaporation \( v \). With a filament having a definite life (1000 hours for instance), therefore, the rate of evaporation in different gases will be the same. Therefore the following is valid for two gases with the diffusion constants \( \gamma' \) and \( \gamma'' \):

\[
v' = \gamma' \cdot T^{\delta}_1 = v'' = \gamma'' \cdot T^{\delta}_2;
\]

(4)

From this it follows that:

\[
\frac{\gamma'}{\gamma''} = \frac{T^{\delta}_2}{T^{\delta}_1}.
\]

(5)

The following is also valid:

\[
\frac{E_2}{E_1} = \frac{\gamma' f}{\gamma'' g}.
\]

(6)

By combining (5) and (6) we find that

\[
\frac{E_2}{E_1} = \left(\frac{T^{\delta}_2}{T^{\delta}_1}\right) \frac{\gamma' f}{\gamma'' g}.
\]

(7)

From the literature it is known \(^4\) that at about 2700° K the following values can be used:

\[
f = 4.8 \text{ to } g = 34.3,
\]

from which it follows that \( f/g = 0.14 \), so that

\[
\left(\frac{E_2}{E_1}\right) = \left(\frac{\gamma'}{\gamma''}\right)^{0.14}.
\]

(8)

From this formula it is found that a large change in the diffusion constant \( \gamma \) of the gas will only cause a relatively small change in \( E \).

The diffusion constants of argon and nitrogen were determined as early as 1917 \(^5\), also as functions of the gas pressure, and from the measurements;

Moreover, it was concluded that the efficiency could be improved by using a gas with a high molecular weight. The results of the measurements were later fully confirmed by experiments by Fonda \(^6\) (see fig. 2).

\[\text{Fig. 2. Rate of evaporation } v \text{ as a function of the pressure } p \text{ (cm mercury), expressed in } \% \text{ of the rate of evaporation in a vacuum.}
\]

\(x\) nitrogen, according to Oosterhuis \(^4\).

\(\circ\) argon with 10% nitrogen, according to Oosterhuis \(^5\).

\(\bullet\) argon with 14% nitrogen, according to Fonda \(^6\).

In addition Fonda \(^7\) fixed the relation between the rate of diffusion and molecular weight in a formula, and pointed out that the calculation of the diffusion can be connected with Langmuir's theory of heat losses.

In this theory it is assumed that the cylindrical filament of thickness \( d \) is surrounded by a cylindrical film (Langmuir layer) of diameter \( b \) in which the gas does not move. According to Langmuir the following expression then holds:

\[
b \ln \frac{b}{d} = k \frac{r}{s}.
\]

(9)

where \( k \) represents a constant, while \( r \) is the viscosity and \( s \) the density of the gas. If, further, \( p \) is the pressure and \( m \) the molecular weight of the gas, then according to Fonda the following formula is found for the diffusion constant:

\[
\gamma = \frac{Cte}{mdp \ln \frac{b}{d}}.
\]

(10)

which we shall make use of in the following.

Comparison of the rates of evaporation in argon and krypton

According to (10) for two kinds of gas at the same


\(^5\) E. Oosterhuis, loc. cit.


pressure the ratio of the diffusion constants \( \gamma' \) and \( \gamma'' \) is the following:

\[
\gamma'' : \gamma' = \frac{\ln (b'/d)}{\ln (b''/d)} \cdot \frac{m'}{m''} \quad \text{(11)}
\]

From this the ratio of the diffusion constants \( \gamma \) of two rare gases, argon and krypton for instance, can be calculated.

The comparison between these two rare gases has become of real importance since the liquid gas industry has succeeded in obtaining krypton on a fairly large scale by a new process\(^8\) which we shall not go into here. Krypton occurs in only extremely small quantities in the air, namely only one millionth by volume.

The molecular weights of argon and krypton are

\[
m_{\text{Ar}} = 40 \quad \text{and} \quad m_{\text{Kr}} = 83.
\]

The viscosities at 20° C are

\[
r_{\text{Ar}} = 2.21 \cdot 10^{-6} \quad \text{and} \quad r_{\text{Kr}} = 2.48 \cdot 10^{-6}.
\]

The densities of the gases are

\[
s_{\text{Ar}} = 1.78 \quad \text{and} \quad s_{\text{Kr}} = 3.71.
\]

As diameter \( d \) of the filament let us choose that of the ordinary 40 Dlm lamp, while it may be remarked that the result of the calculation scarcely changes if one takes for \( d \) the diameter of the filament of a 150 Dlm lamp. Calculating \( b'/d \) of equation (9) and filling this in (11) one obtains

\[
\gamma_{\text{Kr}} = 0.59 \gamma_{\text{Ar}} \quad \text{(12)}
\]

The diffusion constant \( \gamma \) for pure krypton thus amounts to about 60 per cent of that for pure argon. This figure has only a theoretical significance, however, since experience has shown that a filling of pure rare gas cannot be used in lamps for general service. The arcing voltage of rare gases is relatively low, so that in a lamp filled with a pure rare gas an arc may occur between the electrodes which renders the lamp useless. The chance of arcing in the rare gas is considerably diminished when nitrogen is added.

The choice of the proportion of nitrogen will in general be based upon a compromise. Much nitrogen means a decrease in efficiency, little nitrogen increases the chance of arcing.

The most satisfactory nitrogen content cannot therefore be determined on the basis of a limited number of laboratory tests. It is much better to rely upon the experience of many years and the extensive statistical data furnished by the regular lamp testing on the basis of life tests.

In this way in the Philips concern experience has shown that with krypton a content of nitrogen at least 5 per cent higher than with argon must be added, if the same security against arcing of the gas is to be obtained. The arcing voltage of krypton is lower than that of argon.

In order not to make the discussion unnecessarily complicated we shall in the future, when argon and krypton are compared, calculate with the same percentage of nitrogen, namely a content of about 13 per cent which is customary for argon.

By the addition of nitrogen to rare gases the diffusion constant is affected. Fifteen years ago we investigated the rate of evaporation of tungsten wires in different mixtures of argon and nitrogen. It was then found that the rate of evaporation varies proportionally with the nitrogen content (see fig. 3, in which the rate of evaporation determined for krypton and pure xenon are also indicated). From this it follows that it is possible in general to calculate the diffusion constant \( \gamma \) of a gas mixture in a simple way from the ratio of the gases of which the mixture is composed.

![Fig. 3. Velocity of evaporation \( v \) in mixtures of argon and nitrogen as a function of the nitrogen content, expressed in % of the velocity of evaporation in pure argon. For the sake of comparison the velocities of evaporation in pure krypton \( \times \) and xenon \( \square \) are also indicated.](image)

On this basis we have calculated the diffusion-constants \( \gamma \) according to formula (10) for the ordinary lamps of 25, 40, 65, 100 and 150 Dlm with coiled-coil filament, not only of the series for 130 volts but also of that for 220–230 volts, and we have used the values found in equation (8). We then obtained the ratio of the values of \( E \) with a krypton or an argon filling. The \( E \)-values here considered are the ratios of the luminous flux in lumens to the energy \text{radiated} \text{in watts}. In order to be able to compare the results of our calculation with the results of practical measurements, where

---

\(^8\) Ph. Siedler, Angew. Chem., 51, 799, 1938.
the ratio of the luminous flux to the power consumed, the so-called efficiency, is always determined, it is important to recalculate all results on this basis. We began at first with the assumption that the heat losses of the filament to the gas filling are the same for the krypton mixture as for the argon mixture. In fig. 4 the results of the measurement are shown. a) for lamps of low voltage and b) for lamps of high voltage. It may be concluded that for fillings of krypton and argon with the same percentage of nitrogen, the krypton will give an efficiency 4 per cent higher than that of argon, merely as a result of the difference in rate of evaporation for the same filament.

Investigation of coiled-coil lamps with different gas fillings

In order to test the theoretical results of the foregoing section about 50 of each of the 10 types of lamps mentioned were specially made with great care, one half filled with a krypton-nitrogen mixture and the other half with an argon-nitrogen mixture. After having been measured these lamps were subjected to a life test.

From the difference in luminous flux upon transition from argon to krypton the difference in temperature can immediately be calculated, and from that the change in efficiency. These latter figures can also be calculated from the difference in the resistance of the coil. All results are recalculated on the basis of the same life of 1000 hours, while it is assumed that the heat losses to the gas are the same for krypton as for argon.

The values obtained experimentally by both these methods are also included in fig. 4. The points indicated by small circles are obtained on the basis of measurements of the luminous flux and the resistance, respectively.

The theoretically found improvement of the efficiency upon transition from argon to krypton is about 4 per cent, while the experiments gave the result 3.2 per cent. The difference between these two results, while small, may perhaps be explained by the fact that the krypton-nitrogen mixture used already showed some tendency towards arcing and the formation of an arc, which makes the average life of the lamps shorter.

The value of about 4 per cent according to the calculation may therefore be considered as the maximum improvement, upon which one might count only if there were no danger of breakdown of the gas and if the heat losses to the gas were the same for krypton and argon. The somewhat lower value of 3 per cent found practically indicates that there is actually a danger of arcing. In order to eliminate this danger the nitrogen percentage of the krypton mixture should be chosen slightly higher, which would result in a decrease.
in the improvement to be expected to about 3 per cent.

Thermodiffusion

Until now in our discussion we have taken into account only the ordinary diffusion of the evaporated tungsten through the gas. In addition to this there is the so-called "thermodiffusion" which consists in the fact that in the presence of a temperature gradient in a gas mixture the heavier gas diffuses toward the colder zone. This diffusion is more rapid the steeper the temperature gradient and the greater the difference between the densities of the gases.

Since there is a very steep temperature gradient in the Langmuir film a considerable thermodiffusion of the heavy atoms of the vapourized tungsten may be expected; this diffusion will be more rapid in the lighter argon than in the heavier krypton. The rate of diffusion of tungsten in krypton should therefore be less than the 59 per cent of that in argon indicated by formula (13).

Since the rare gases used are not pure, but are mixed with nitrogen, the influence of the nitrogen on the thermodiffusion must still be ascertained. The latter gas in the mixture is also subject to thermodiffusion. As the lighter component it will diffuse toward the filament, so that there the gas mixture will be richer in nitrogen. Around the filament, therefore, the average density of the gas atmosphere is less than that of the gas mixture used for filling. The addition of nitrogen to the rare gas increases the diffusion and thus has an effect opposite to that which results from the transition from argon to krypton.

From the experiments it may be concluded that it is unnecessary to introduce a correction for the thermodiffusion into formula (10) since the experimental results do not lie above, but always below the results of the calculation.

Colour difference between argon and krypton lamps

From equation (5), since the ratio of the diffusion constants and the exponent $g$ are known, the increase in temperature can be calculated upon the transition from the argon to the krypton mixture. For the ten types of lamps specially made for this investigation it amounts on an average to

$$\Delta T = 0.0125 T = 34 \degree K \text{ (calculated).}$$

From the optical and electrical data we found for these types of lamps the increase in temperature given in table I.

<table>
<thead>
<tr>
<th>$\Delta T$, calculated from the increase in the light flux</th>
<th>$\Delta T$, calculated from the increase of the resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>38 $\degree K$</td>
<td>45 $\degree K$</td>
</tr>
<tr>
<td>14</td>
<td>24</td>
</tr>
<tr>
<td>32</td>
<td>28</td>
</tr>
<tr>
<td>28</td>
<td>32</td>
</tr>
<tr>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>29</td>
<td>24</td>
</tr>
<tr>
<td>29</td>
<td>21</td>
</tr>
<tr>
<td>28</td>
<td>20</td>
</tr>
<tr>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>15</td>
<td>21</td>
</tr>
</tbody>
</table>

average 26.3 $\degree K$ 26.5 $\degree K$

From this table it is evident that no systematic variation of $\Delta T$ with the luminous flux of the lamps investigated could be derived. The mean error is about 7°. The increase in the true temperature of a tungsten filament upon the transition from an argon to a krypton mixture as filling for the bulb, therefore, is an average of

$$\Delta T = 0.0098 T = 26° \pm 7°.$$

An investigation of krypton and argon lamps, as put on the market, with the help of the pyrometer gave a slightly lower average value for the difference, namely 20°, which may be explained by the somewhat higher nitrogen content in krypton lamps.

It need hardly be stated that it is impossible to perceive a temperature difference of 1% in electric lamps without optical instruments. This can easily be verified by a simple and yet technically convincing test. A krypton and an argon lamp are screened from each other and each used to illuminate part of a white surface. It is impossible to determine a colour difference with any degree of confidence.

Efficiency and heat losses

Since a considerable part of the energy which is taken by an electric lamp with gas filling is lost by direct heat conduction to the gas, we shall examine the influence of this on the efficiency somewhat more carefully. In the case of the 40 Dlm lamp for 220—230 volts, which is the most commonly used gas-filled lamp with single coil, almost 33 per cent of the energy was lost in this way, since it did not contribute to the light radiation. One of the means
of decreasing this loss and thus increasing the efficiency consists in using gases for filling, which have a poor heat conductivity.

According to Langmuir the heat which a cylindrical filament gives off at the temperature \( T \) per cm length to the surrounding gaseous atmosphere with a temperature of 300 °K, is determined by the equation

\[
W = \sigma \left( \varphi_T - \varphi_{300} \right),
\]

where

\[
\sigma = \frac{2\pi}{\ln \left( \frac{b}{d} \right)}, \quad \varphi = 4.19 \cdot \int_0^T \lambda dT,
\]

and

\[
\varphi = 4.19 \cdot \int_0^T \lambda dT,
\]

while \( b \) = the diameter of the Langmuir film, 
\( d \) = the diameter of the filament, 
\( \lambda \) = the heat conductivity of the gas.

The heat conductivity \( \lambda \) could be calculated with the help of Sutherland’s formula for the viscosity and from the specific heat at constant volume. The constants occurring were taken from the Landolt-Börnstein tables.

The calculation of \( \left( \varphi_T - \varphi_{300} \right) \) for different temperatures \( T \) of the filament gave the values shown in table II for nitrogen, argon and krypton.

<table>
<thead>
<tr>
<th>( T ) (°K)</th>
<th>( N_2 )</th>
<th>( \text{Ar} )</th>
<th>( \text{Kr} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>0.293</td>
<td>0.216</td>
<td>0.124</td>
</tr>
<tr>
<td>1500</td>
<td>0.623</td>
<td>0.453</td>
<td>0.264</td>
</tr>
<tr>
<td>2000</td>
<td>1.030</td>
<td>0.743</td>
<td>0.438</td>
</tr>
<tr>
<td>2500</td>
<td>1.506</td>
<td>1.083</td>
<td>0.642</td>
</tr>
<tr>
<td>3000</td>
<td>2.047</td>
<td>1.451</td>
<td>0.868</td>
</tr>
</tbody>
</table>

When these values are represented in a graph with a double logarithmic scale (see fig. 5) they lie on a straight line for each gas, at least the values for 2000°, 2500° and 3000° K in which we are interested, so that we may represent \( \left( \varphi_T - \varphi_{300} \right) \) in this temperature region which is important for electric lamps by the formula:

\[
\varphi_T - \varphi_{300} = \alpha_1 \cdot T^\beta, \quad \ldots \ldots \ldots (16)
\]

or also

\[
\varphi_T - \varphi_{300} = \alpha \left( \frac{T}{2700} \right)^\beta, \quad \ldots \ldots \ldots (17)
\]

where we assume that 2700 °K is approximately the average temperature of the tungsten filament.

The constants \( \alpha \) and \( \beta \) then take on the values in table III.

<table>
<thead>
<tr>
<th></th>
<th>( \alpha )</th>
<th>( \beta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>1.70</td>
<td>1.65</td>
</tr>
<tr>
<td>Argon</td>
<td>1.22</td>
<td>1.65</td>
</tr>
<tr>
<td>Krypton</td>
<td>0.73</td>
<td>1.65</td>
</tr>
</tbody>
</table>

In order to calculate the losses by heat conduction by the gas, in addition to \( \left( \varphi_T - \varphi_{300} \right) \) the "shape factor" \( \sigma \), which occurs in (13) must also be known. Langmuir gives the following formula for this:

\[
\frac{d}{B} = \frac{\sigma}{\pi} \cdot e^{-2\pi/\sigma}, \quad \ldots \ldots \ldots (18)
\]

where \( d \) again represents the diameter of the filament and \( B \) is the thickness of the Langmuir film for a plane surface. This formula corresponds to (9) with

\[
k = \frac{s}{r} = 2B \quad \ldots \ldots \ldots (19)
\]

For air with a pressure of 76 cm of mercury, according to Langmuir’s measurements,

\[
B = 0.43 \text{ cm}.
\]

Langmuir has further assumed that \( B \) is proportional to the ratio of the viscosity and the density, so that from the known data \( B \) can be calculated for the different gases.

For a pressure of 57 cm one then finds that:

- for nitrogen \( B_N = 0.57 \text{ cm} \),
- for argon \( B_{Ar} = 0.51 \text{ cm} \), and
- for krypton \( B_{Kr} = 0.27 \text{ cm} \).

From equation (18) it is now possible to calculate \( \sigma \) and thus also \( W = \sigma \left( \varphi_T - \varphi_{300} \right) \).
For \( T = 2700 \, ^\circ \text{K} \) one then obtains the heat losses given in table IV in W/cm for different diameters of the filament with rare gas mixtures containing 13 per cent of nitrogen.

Table IV

<table>
<thead>
<tr>
<th>Diameter of the filament in ( \mu )</th>
<th>W/cm (2700 , ^\circ \text{K}, 57 cm of mercury)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \text{N (pure)} )</td>
</tr>
<tr>
<td>100</td>
<td>3·08</td>
</tr>
<tr>
<td>200</td>
<td>3·62</td>
</tr>
<tr>
<td>300</td>
<td>4·01</td>
</tr>
<tr>
<td>400</td>
<td>4·35</td>
</tr>
<tr>
<td>500</td>
<td>4·66</td>
</tr>
<tr>
<td>700</td>
<td>5·18</td>
</tr>
<tr>
<td>1000</td>
<td>5·65</td>
</tr>
</tbody>
</table>

If the dimensions of the filament are known the energy lost by heat conduction can be calculated for the different gas mixtures, and on the basis of that, the way in which the efficiency is changed can be determined. This calculation was carried out for the ten specially made types of lamps; the results, for an argon mixture as well as for a krypton mixture are given in fig. 6.

It may be seen that when the argon mixture is replaced by a krypton mixture the efficiency in Dlm/W increases on an average of 3.6 per cent due to the smaller heat losses, when we assume that the rate of evaporation of tungsten is the same in argon as in krypton. This value will, however, fall to 2-3 per cent, when, taking into account the greater chance of arcing in krypton, more nitrogen is added than is customary in the case of argon.

Final considerations

In this article we have studied successively the influence of the form of the filament and of the composition of the gas filling on the efficiency of lamps, the average life remaining the same. By passing over from single coil to coiled-coil filaments of the same luminous flux and life, an improvement of an average of 15 per cent the efficiency was obtained. With this, however, the possibilities of development of the gas-filled lamp are by no means exhausted. Since the introduction of lamps with coiled-coil filaments a further improvement of the efficiency of this type has been obtained on the basis of earlier fundamental research \(^{10}\), which, however, we shall not go into here.

According to the discussion given in this article it might be expected that by making use of krypton instead of argon for filling coiled-coil lamps a further improvement could be obtained as a result of the differences in rate of evaporation and in heat conduction. It must, however, be kept in mind that the improvement relates to the initial value of the efficiency. Since, however, during use this last quantity decreases more rapidly with krypton lamps than with argon lamps, in practice only a slight improvement will be obtained. Especially in large types of lamps this phenomenon occurs, be-

\(^{10}\) E. Oosterhuis, loc. cit.
cause due to the high cost of krypton relatively small bulbs must be used for krypton lamps, so that they become blacker than is the case with the corresponding argon lamps. In agreement with this we found that the lamps on the market with krypton filling and coiled coil, compared with our corresponding coiled-coil argon lamps of the same luminous flux, exhibited an improvement of 3 per cent in the efficiency throughout life. To what degree it is in general justifiable to realize this improvement, considering the cost of the krypton filling, is an economic problem which we shall not discuss here.

In general that development will be preferable by which a technical advance can be attained without an intolerable increase in production costs, and with which, moreover, the new lamp can replace the existing type almost completely. A further requirement of the general utility of a new technical improvement is that it shall not have a retarding action on later possibilities of development. The coiled-coil lamp filled with argon and in normal dimensions satisfies these conditions. In recent years it has gained an absolutely dominating position with the result that the former lamp with single coil has practically become obsolete while it leaves the path open for further improvements in the future.

---

ON THE CONSTRUCTION OF VIBRATORS FOR RADIO SETS

by J. KUPERUS.

Several problems are discussed, which are connected with the construction of vibrators for the connection of an A.C. receiving set to the D.C. mains. The study of these problems has led to the development of a new type of vibrator which is described.

A description has already been given in this periodical of a vibrator which serves for the connection of A.C. receiving sets to the D.C. mains \(^{1}\). In this article we shall discuss a number of problems connected with the construction of such vibrators and describe a new type of vibrator in which various improvements are incorporated.

The connections of a vibrator are represented diagrammatically in fig. 1. The springs \(A_1\) and \(A_2\), which are insulated from each other electrically but joined mechanically, can alternately make contact against \(K_{11}\) and \(K_{12}\) and \(K_{22}\) and \(K_{21}\), respectively. The springs are moved by the electromagnet \(M\) acting on an armature which is mechanically connected with the springs \(A_1\) and \(A_2\). When these springs are in the stationary state the spring \(A_1\) is connected with the coil of the magnet by means of the contact \(K\). When the vibrator is connected to the D.C. mains the electromagnet will attract the armature and contact will be made between \(A_1\) and \(B_1\) and between \(A_2\) and \(B_2\). At the same time the contact \(K\) is broken so that the armature is no longer attracted. Due to the effect of inertia the springs continue to move still farther and then swing back through the stationary state, making contact between \(A_1\) and \(B_2\) and \(A_2\) and \(B_1\); respectively. Due to the fact that the magnet is again excited each time in a suitable phase of the vibration of the springs, the mechanism keeps itself going. A current thus flows through the primary winding of the transformer which continually changes its direction, so that in the secondary winding an A.C. voltage is induced whose magnitude depends upon the voltage of the D.C. mains, among other factors, and on the ratio of the number of windings of primary and secondary coils of the transformer.

Due to the self-induction of the transformer and the magnet coil, with connections like those of fig. 1, a high voltage would occur between the points of

---

\(^{1}\) Philips techn. Rev., 2, 346, 1937.