Some recent developments in rare-gas discharge lamps

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Although the luminous effect produced by the discharge of electricity through gases at low pressures has been known for many years, and the Moore tube was in use as long ago as 1907, the further development of discharge tubes giving light of very high intensity is a quite recent achievement. Originally capable of giving only an intermittent light, very efficient 'gas arcs' have now been constructed which will continuously emit a brilliant white light.

INTRODUCTION

The luminous and other radiations produced by the electric discharge through rarefied air and other gases have been studied for many years. With the notable exception of the Moore tube, introduced in a commercial form in 1907, early gas-filled devices were of little or no value for purposes of general illumination. In view of its historical importance in relation to later developments, it is worth while to consider the Moore lamp in some detail. It consisted in general of a length of glass tubing of the order of 200 ft which was built up and processed *in situ*. The best results appear to have been obtained with tubing 1¾ inches in diameter; the colour and efficiency of the light depended on the gas in the tube. In some tubes, nitrogen was used and gave a soft golden light, and in others carbon dioxide, which gave a white light similar to that of the north sky.

Of the rare gases of the atmosphere only neon was found to yield a commercially useful light-source, and, largely owing to the work of Georges Claude, the neon tube for advertising and display purposes became the first rare-gas discharge lamp. It was first demonstrated in 1907, and was the forerunner of a whole range of high-voltage cold cathode discharge tubes which produced a variety of colours; the basic discharge in most cases, however, depended upon either neon or neon-argon and mercury vapour mixtures.

At a later date, fluorescent coatings on the inside of high-voltage discharge tubes were introduced, and the range of possible colours was greatly increased. These lamps in turn eventually led to the mains-voltage fluorescent lamp, which is becoming of considerable importance for general lighting purposes.

During the late nineteen-thirties, the author and his colleagues began a series of investigations involving the passage of heavy current discharges through the rare gases. By 1939, preliminary data had been obtained on discharges in which currents of many amperes were passed through boro-silicate glass tubes about 1¼ inches in diameter, containing neon, argon, and helium at comparatively low pressures.

It was found that the spectrum of the radiation was similar to that obtained with the Claude tubes, which generally worked at a current of only 25–50 milliamperes. The efficiency of light production was, however, low, owing to the fact that, although low-loss emissive electrodes were used, the voltage drop in the experimental lamps was only of the order of 30, the arc length being limited to about 20 cm. It was considered that the range of pressure and current conditions which ought to be investigated would require a different type of tube, and probably new circuit techniques, if the obvious possibilities were to be explored in even a preliminary manner. The object was to produce a concentrated-source gas-discharge lamp of high efficiency.

WORK ON CONDENSER DISCHARGES

Notwithstanding the lack of success of earlier attempts to produce a high-efficiency light source using the rare gases, it was felt that the possibility existed of producing a concentrated source provided that sufficient energy could be discharged through the gas. The capacitor discharge technique, for example, had been used successfully for many years for producing short-duration sparks in air. The substitution of a gas discharge tube for the air spark gap was an obvious development, and this method had been investigated by Edgerton and others.

In principle, the method was to charge a capacitor to a high voltage, and then to cause the lamp,

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which was permanently connected across the capacitor terminals, to become conductive by the production of an ionizing high-voltage high-frequency discharge on its walls. The conductive state would then build up to a maximum in a few microseconds, and the energy in the capacitor would discharge very rapidly through the lamp.

In early experimental work in the author's laboratories[1] using this technique, boro-silicate glass tubes of various lengths and diameters had a filling of a few mm of argon and a low pressure of mercury vapour. The object at this stage was to produce a very high current density discharge through low-pressure mercury vapour, but a spectroscopic examination of the radiation revealed that very little mercury vapour was present and that the discharge was being carried almost entirely by the rare gas.

It was therefore decided to investigate condenser discharges through the rare gases alone. Some interesting results were immediately obtained. It was found that as the energy discharged through the tube increased, the quality of the radiation changed, and spectrographs revealed that continuous radiation eventually developed at the highest current densities, and that the characteristic line spectrum of the gaseous element in the tube became less dominant (see figure 1). Eventually, tubes were produced in which an inner or guide tube was flanged at each end, but only one of the flanges was sealed into the outer tube. This device was adopted to allow expansion and movement of the inner tube under the shock-wave and temperature-rise which take place when the pulse discharge passes.

It was found that such tubes would carry considerable currents for very short periods of time; some typical data are given in the table below.

TABLE

Type	*Joule rating*	*Approx. lumen sec*	*Effective duration (microsec)*	*General use*
SF4	400	16,000	450	Scientific purposes
SF5	200	7,000	350	
SF6	100	3,000	200	

It was observed during the course of the work on this type of discharge that the arc did not completely fill the bore of the tubing (see figure 3, which shows a 200-joule discharge through a xenon-filled tube). Such photographs made it possible to measure the approximate width of arc, from which it was calculated that the average current density in the discharge was of the order of at least 1000 amperes per square centimetre.

Observations of this kind, together with measurements of the luminous efficiency of the discharge, indicated that the development of continuous radiation from the flash-discharge tube coincided with the development of relatively high efficiency. Careful measurements of the total flux from the SF4 tube, taken in conjunction with the energy discharged from the capacitor, showed that efficiencies of the order of 40 lumens per watt were possible in the xenon-filled tube, and about 30 l/W in the krypton-filled tube. In each case the colour of the radiation was white, and the distribution of spectral energy was not dissimilar to that of daylight, although there was a predominance of energy at the blue end of the spectrum over and above that present in daylight. Eventually a range of some ten types of tube was produced, and many uses have been found for these repeating flash-tubes, not only of the earlier linear form but also in more compact forms in which the discharge tube proper is wound into a helix of the type shown in figure 2.

The development of a highly efficient white-light source of intermittent character stimulated work on the production of a continuously burning rare-gas light-source of daylight quality and high efficiency, and eventually in 1947 the successful production of the gas arc was announced.

THE GAS ARC

The term 'gas arc' has been applied by the author to rare-gas discharge lamps operated under arc conditions which cause them to emit radiation of daylight quality. The radiation from the gas arc is characterized by an intense continuum extending from the ultra-violet through the visible region into the infra-red. It had been observed previously by the author and his colleagues that, while the low-pressure discharge through argon produced a bluish radiation of low intensity and efficiency, at higher pressures and with very high current densities argon could be excited to produce an intense white light of high efficiency. By comparison with the results obtained in the flash tube, the possibilities with krypton and xenon appeared even more favourable, and it was decided to investigate their behaviour over a range of pressures and current densities. In essence, the problem was to determine whether with available

[1] Aldington, J. N., 'The High-intensity Flash-discharge Tube,' ENDEAVOUR, 7, 21, 1948.

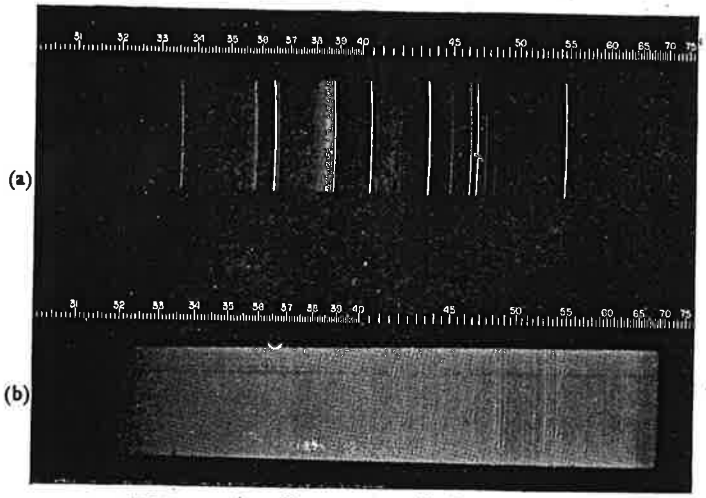

FIGURE 1 – (a) *Low-current discharge through krypton.* (b) *High-current discharge through krypton.*

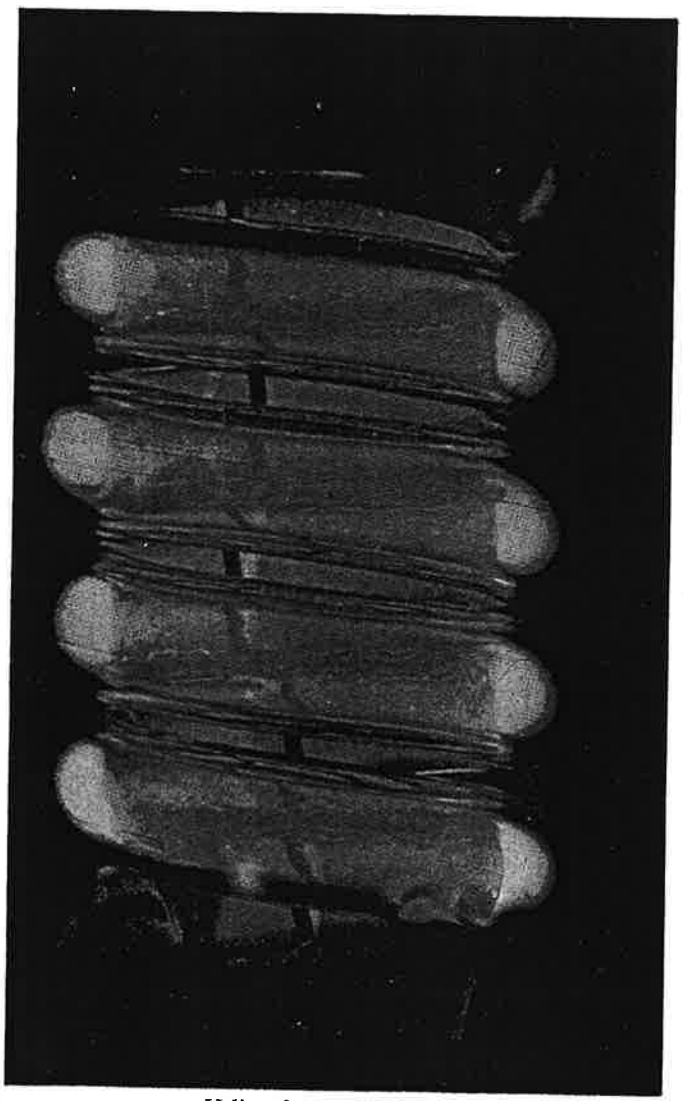

FIGURE 2 – *Helix of compact type of flash-discharge tube.*

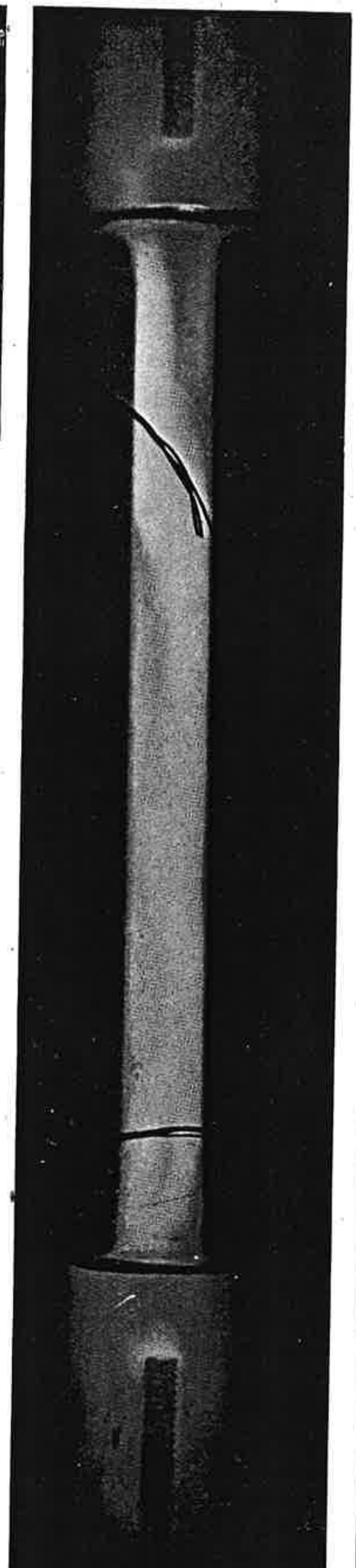

FIGURE 3 – 200-*Joule discharge through xenon-filled tube.*

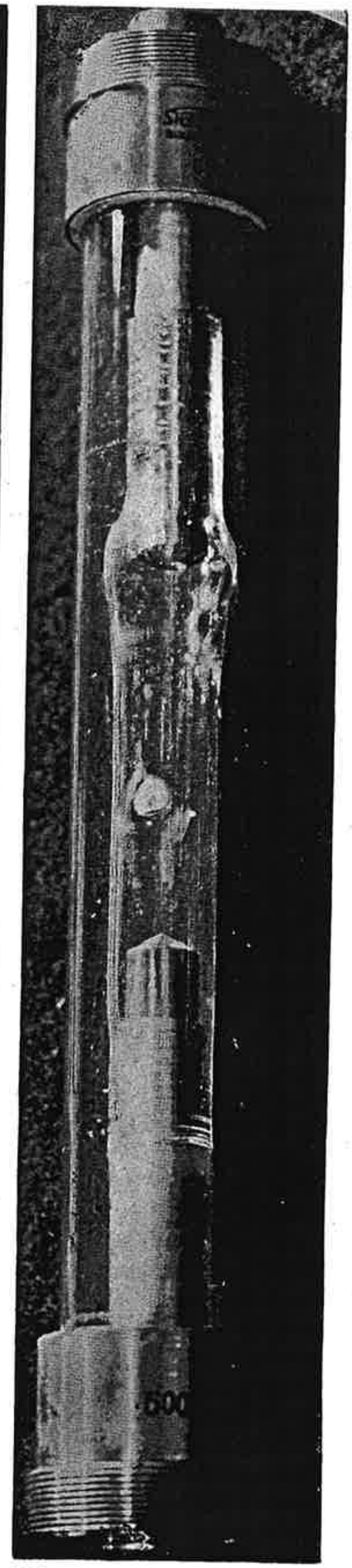

FIGURE 4 – *Complete gas arc in water jacket.*

materials it was possible to excite the rare gases, either singly or in mixtures, to such an extent that a continuous background spectrum was obtained, and secondly to determine whether under such conditions a practical lamp with a reasonably high efficiency would result.

In considering the development of any discharge tube in which a particular gas has to be hermetically sealed there are a number of obvious but important factors of which it is necessary to take account. These factors include the temperature which will be attained by the walls of the containing vessel, the temperature reached by the electrodes when the discharge is passing, the physical and chemical stability of the electrodes, and the material of the containing vessel exposed to the discharge. The ideal to be pursued is obviously a discharge lamp with an envelope consisting of a transparent refractory substance which will remain completely unchanged under the influence of the discharge; electrodes which suffer little or no sputter or evaporation during life; and a gas-filling which emits its full light output of daylight quality, and at high efficiency, immediately the lamp is switched into circuit.

It was found in the earlier work, and as shown in figure 3, that a constricted discharge occurred in krypton and xenon at quite low pressures. The effect is related to the high atomic weights and low mobilities of these elements. Such a constricted discharge tends to be very mobile, and is easily influenced by convection currents and electrical fields. It was therefore considered necessary for the practical attainment of a suitable discharge that the arc itself should be closely confined, and that convection currents set up in the gas should be restricted by the design of the envelope.

Such considerations suggested the use of a lamp of tubular form and of comparatively high loading. The general considerations outlined above made it clear that the only practicable material for the containing vessel would be quartz. Eventually, for a loading of 5 kW a quartz tube of about 12 mm bore, and with 6·5 cm between the electrodes, was chosen. It was necessary to cool the quartz tube in a stream of running water, and the completed gas arc is shown in figure 4.

The electrodes consisted of polished rods of tungsten containing 5 per cent. of thoria, the ends of the rods being tapered so that the arc was centred on the conical electrode tips. They were designed to fill the inside of the quartz tube closely, and at the ends remote from the arc-space they terminated in molybdenum sealing foils. During the construction of the lamp these foils were sealed *in vacuo* between the outer quartz tube and an inner quartz member, in a manner developed previously for the production of mercury-vapour arc lamps of high current-density.

The gas arc is essentially a high-current, low-voltage device. With a loading of 5 kW the current is of the order of 80 amperes and the arc drop between the electrodes of the order of 65 volts.

In parallel with this work on gas arc lamps of tubular form, experimental work has also been carried out on air-cooled gas arc lamps made from quartz and filled with xenon, similar to certain high-pressure mercury vapour lamps. If the distance between the electrodes is made quite short—of the order of 15 mm—it is possible to obtain an arc brightness of the order of 25,000 candles per square centimetre with a loading of 3 kW.

PROPERTIES OF THE GAS ARC

The water-cooled xenon-filled gas arc with a loading of 5 kW has an efficiency of about 30 l/W. A similar efficiency has been obtained with short arc-length air-cooled forms, and efficiencies as high as 40 l/W have been obtained with experimental linear forms of air-cooled lamp, designed in such a way that the arc voltage was of the order of 100.

The gas arc has a positive volt-ampere characteristic, but it is desirable to operate it in a similar way to other electric discharge lamps, namely in series with a current-limiting device, such as a resistance for direct currents or a reactance for alternating currents. When the lamp is in operation, the current can be varied over a wide range, and an important characteristic is the fact that, with change in arc current, there is only a second-order change in the colour of the radiation.

Compared with other light sources the gas arc has the following characteristics:

1. Excellent colour (similar to that of daylight).
2. Comparatively cool radiation (owing to the water-cooling).
3. Immediate attainment of full light output.
4. Considerable concentration of the light source (the water-cooled 5 kW gas arc has an average brightness of 5000 candles per square centimetre).

Of these properties, perhaps the most important is the fact that in the gas arc we have a light source which can be switched on and off at will, and in which full light output of daylight quality is immediately attained.