VOL. 1 No. 7 JULY 1936

Philips Technical Review

DEALING WITH TECHNICAL PROBLEMS
RELATING TO THE PRODUCTS, PROCESSES AND INVESTIGATIONS OF
N.V. PHILIPS' GLOEILAMPENFABRIEKEN

EDITED BY THE RESEARCH LABORATORY OF N.V. PHILIPS' GLOEILAMPENFABRIEKEN, EINDHOVEN, HOLLAND

IRRADIATION OF PLANTS WITH NEON LIGHT

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Summary. Owing to the want of light the growth and development of plants during the winter becomes considerably arrested. This check may be completely or partly counterbalanced by irradiating the plants with artificial light. Owing to its favourable spectral distribution neon light is particularly suitable for this purpose. The technical development of neon light sources for plant irradiation and the irradiation conditions laid down by Roodenburg on the basis of extensive experimental work now permit the commercial grower and the amateur horticulturist to promote the growth of their plants by irradiation.

After decades of abortive experiments in the Netherlands and elsewhere on the artificial irradiation of plants, an appreciable measure of success has recently been achieved in this direction. That light is one of the principal factors in the growth of plants has been realised for many years, and the idea has long been entertained of attempting to influence the growth and development of plants by irradiation with artificial light. But only with the technical development of the requisite sources of light has a fundamental investigation of this problem been made possible and enabled the market grower and amateur horticulturist to employ irradiation methods on a practical scale.

Composition of light for the irradiation of plants

The life and growth of plants are intimately connected with certain chemical processes. One of the chief of these is the assimilation of carbon dioxide, in the course of which the plants absorb carbon dioxide from the air and the carbohydrates from the water of which plants are principally built up. Carbon dioxide assimilation takes place only when a light stimulus is provided, the light being absorbed by the green colouring matter of the leaves, viz, chlorophyll. If the light available for the plant drops below a specific level, e.g. during the short days of winter, growth is practically static, even though all other conditions for their growth are adequately met, as for instance by placing in heated and moist greenhouses and by the addition of suitable fertilisers.

By augmenting the natural light with an auxiliary source of illumination, it has now been possible to promote the growth of plants even during the darkest winter months.

Carbon dioxide assimilation is most active in red light, which is absorbed to a high degree by chlorophyll. Hence, in providing auxiliary irradiation for plants, it is essential to utilise a source of light containing a sufficient concentration of red rays. At an early date it was therefore proposed to employ neon light for this purpose [1]). *Fig. 1* shows the spectrum of a neon light source and the assimilation curve, the latter indicating the amount of carbohydrate formed on irradiation with an equivalent light energy of each wavelength. Neon has the most intense lines just in that region in which the effect of light on carbon dioxide assimilation is greatest. The same figure also gives the spectrum for an ordinary glowlamp. The greater part of the radiation from the glowlamp consists of infra-red (invisible) rays and only 8 per cent of its radiation is situated in the visible spectrum, whilst about 20 per cent of the total energy radiated from the neon tube lies in this region. But since glowlamp light is much easier to generate and to manipulate than neon light, experiments have also been carried out on the irradiation of plants with glowlamp light. In the first place it is necessary to produce an adequate intensity of red

[1]) G. Höstermann: Experiments with neon light. Bericht Königl. Gärtnerlehranstalt Dahlem, 1916-17, p. 76.

light. This can be readily obtained with high-power glowlamps, although at the same time an immeasurably greater amount of energy is also radiated in the undesirable region of the spectrum.

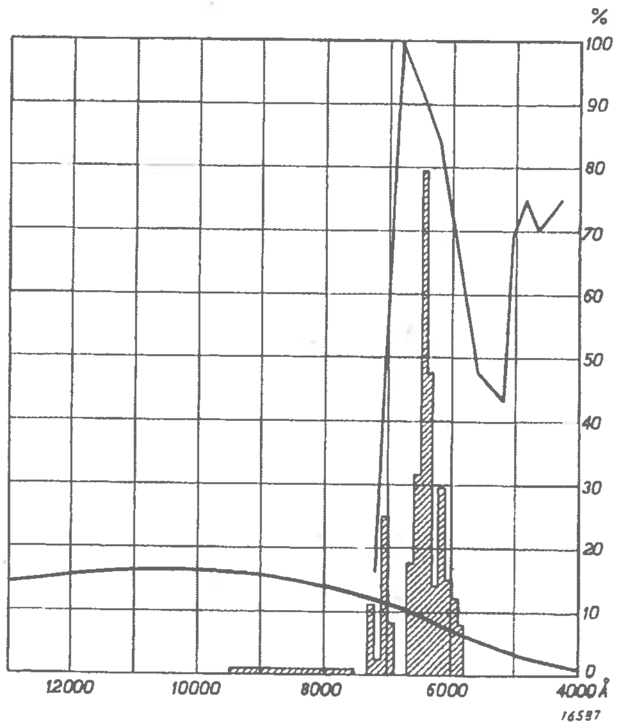

Fig. 1. Assimilation curve of plants, giving the relative amount of carbonhydrate formed on irradiation with a specific light energy at each wave length. The spectra for a neon light source and an ordinary glowlamp are also included. The strongest neon lines are situated exactly in that region of the spectrum of principal importance to assimilation, whilst maximum radiation from the glowlamp is obtained at much higher wave lengths, viz, in the infra-red.

Investigations made by Roodenberg [2]) gave a fresh insight into this problem in so far as they demonstrated that excess infra-red rays were not only superfluous but even deleterious to the plants. Nearly all investigators have found with glowlamp light that, although the growth of the leaves was promoted in the irradiated plants, the general quality of the plants suffered, as the stems and stalks grew too "leggy". This "legginess" is due to the high percentage of infra-red heat rays given out by glowlamps [3]).

[2]) J. W. M. Roodenburg: Kunstlichtcultuur, October, 1930 and December, 1932. Meded. Landbouwhoogeschool Wageningen, vol. **34**, No. 8 and vol. **36**, No. 2. (Published by R. Veenman, Wageningen.)

[3]) In some cases it is mainly a question of rapid growth, as in the germination of seeds and bulb culture, etc. No carbohydrates need be formed in these instances, their formation taking place at the cost of reserve bodies which have been accumulated in the bulb. With these plants, growth may be equally well promoted merely by increasing the temperature; "light" is of no specific value here.

As we have already seen, neon light also contains infra-red radiation, although there is here not the same disproportion between the infra-red and the red rays as found with the glowlamp. Moreover, the distribution of the radiated energy over the various parts of the infra-red region is here quite different, as is shown in *fig. 2*. The "infra-red" has here been divided up into three almost arbitrary ranges, viz, from a wave length of 0.8 to 1.3 μ, from 1.3 to 3 μ, and above 3 μ. The "visible" wave lengths extend from 0.4 to 0.8. Neon light radiates an adequate amount of energy in the first (visible) range, almost none at all in the second and third ranges and a very large proportion in the last range (above 3 μ). A glowlamp, on the other hand, which in the visible spectrum gives the same amount of radiation energy as the neon tube, radiates light rays principally in the two ranges of 0.8 to 1.3 and up to 3 μ. It is, moreover, probable, although not yet confirmed by experiments, that the infra-red radiation in the range from 0.8 to 3 μ causes more "legginess" in plants than the very long wave radiation 3 μ. For the latter radiation is already radiated to a considerable extent by the heating arrangements provided in greenhouses and living rooms.

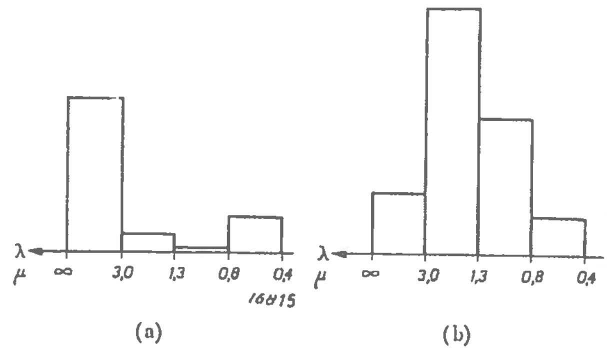

Fig. 2. Infra-red radiation in neon light (*a*) and in glowlamp light (*b*). The infra-red range is divided into three fairly arbitrary parts. The ratio of visible to infra-red radiation is much less favourable with the glowlamp than with the neon tube. At the same time radiation between 0.8 and 3 μ, which probably is mainly responsible for the unwanted "legginess" of plants, is almost completely absent in the neon light, whilst it constitutes the greater part of radiation from the glowlamp.

The points outlined above have been confirmed by a large number of experiments on a wide variety of plants, in which the neon light was found exceptionally suitable for plant irradiation. In *figs. 3* to *6* a few of the results arrived at in these experiments are reproduced. The general observation may be made that apart from more rapid growth larger leaves are also formed, which owing to the greater amount of chlorophyll formed are coloured a dark green [4]), the stems are thicker, the roots are stronger, and frequently the formation of fruit and blooms is also much promoted.

Dosage of irradiation

Similar to the procedure dictated in irradiation treatment for medical purposes, the application of the correct dosage is also a most important factor in the irradiation of plants if successful results are to be obtained. The correct dosage can also be established by actual experiments, and is determined by two factors: The radiation intensity to be used and the time during which the plants are exposed to irradiation. Important experimental data have already been collected regarding this question, particularly by the Agricultural College at Wageningen. It is evident that in these experiments the "efficiency" of irradiation has also had to be given consideration in view of the practical adoption of the method by market growers: The costs of irradiation must be in reasonable proportion to the extra return which well-developed plants will fetch.

As regards the requisite intensity of irradiation, the experiments have shown that with the majority of plants very good results can be obtained with an illumination intensity of 500 to 1000 lux. For purposes of comparison it may be stated that the mean illumination on a December day at about 3 o'clock in the afternoon is roughly 3000 lux and during the evening on a sufficiently illuminated desk about 200 lux.

Turning to the irradiation times, it is possible to regulate the "light diet" of the plants in a variety of ways. Consideration must be given to the stage of growth at which the plants are irradiated, furthermore for how many weeks or months irradiation is to be applied and how many hours each night. In general an irradiation period of 8 hours nightly is recommended, e.g. from 10 p.m. to 6 a.m. It does not lie within the scope of this article to set forth full instructions for irradiating plants, such as have been worked out on the basis of the research carried out at Wageningen referred to above, particularly as the instructions vary according to the genus of the plants.

[4]) This result is frequently observed after only a few nights' irradiation.

The irradiation of Star of Bethlehem (Campanula isophylla) may, however, serve as an example. This plant, which is slipped and potted in spring and is disbudded as much as possible during the summer, is usually transferred to the forcing house about the first of September. About the middle of November irradiation with neon light is commenced (at a forcing house temperature of 15 °C.). During the first few weeks little result is to be seen, although the irradiated plants very soon acquire a fine dark-green colour. During December the growth of the plants is rapid and large leaves and stout stems are formed. At the end of January, when the plants have borne a host of buds, irradiation can be terminated. Irradiation is therefore only applied during the budding period. As early as the beginning of February the first buds will open on the irradiated plants (see the photograph in fig. 3).

Plant irradiation equipment. Neon tubes

At the time neon lights were introduced for the irradiation of plants, they had already been employed for several years for luminous advertisements. The neon light sources used for these purposes consisted of a long glass tube, into the ends of which two iron electrodes were fused, and containing a neon filling at a pressure of approx. 10 mm. They were run on high tension (e.g. 3000 volts) and emitted a comparatively small luminous flux per metre of tube length (160 lumens per m). The use of high tension in damp forcing houses for the irradiation of plants met with serious objection as well as the low brightness of the high-tension tubes. To obtain the requisite illumination of at least 500 lux

Fig. 3. Star of Bethlehem (Campanula isophylla). Picture taken on February 5, 1934. Left: Irradiated with neon light, 600 lux, each night from 10 p.m. to 6 a.m. from November 2, 1933, to January 25, 1934. Right: plants non-irradiated.

Fig. 4. Strawberry, var. "Deutsch Evern." Potted in the open. July 19, 1935: transferred to forcing house October 2.
a) Picture taken on December 7, 1935. Left: Irradiated with neon light, approx. 450 lux, nightly 10 p.m. to 6 a.m. Right: Non-irradiated plants.
b) Picture taken February 28, 1936 (towards the end of the crop). Left: Irradiated as at (a). Right: Non-irradiated plants.

a tube already about 5 m long was required for 1 sq. m of radiation surface.

The illumination intensity could only be increased at that time by raising the current intensity, but with the then normal pressure (10 mm) of the neon filling this had a very adverse effect on the efficiency and the life of the tubes. A satisfactory efficiency could only be achieved with a pressure of 1 mm and below, or by increasing the current density in the tubes ten times. This lower pressure, however, led to a pronounced disintegration of the iron electrodes due to ionic bombardment resulting from the high voltage drop at the cathode in this range (approx. 300 volts); the life of a low-pressure neon tube was thus reduced to a few hours. Amelioration was afforded by the use of hot cathodes, which owing to their electronic emission reduced the cathode fall to a few volts and enabled the tubes to be run on low-tension. Modern gas-discharge lamps for highway lighting are also constructed on this principle. Compact high-power units are thus obtained, operating with currents of a few amperes instead of for instance 25 milliamps in the case of high-tension tubes. A selection of early and

Table I. Dimensions and Data of a High-tension Neon Tube (*H*) and Three Low-Tension Neon Tubes (Type Nos. 4307, 4309, 4311).

Tube	Running voltage volts	Overall diameter mm	Length of light column m	Tube current amps	Consumption watts	Light output lumens	Gross light yield lumens per watt
H		13—14	2	0.025	36	320	9
4307	380	40—43	1.5	3.0	500	8750	17.5*)
4309	220	45—48	1	4.5	450	6300	14
4311	220	16—18	0.35	0.95	90	1200	14

*) The light yield of the neon column after substracting the losses in the input unit and at the electrodes is in this case 26.5 lumens per watt.

Fig. 5. Gloxinia, var. Kaiser Friedrich. Bulbs planted Nov. 11, 1932. Picture taken on April 3, 1933, i.e. one month after end of irradiation period. Left: Irradiated with neon light, approx. 800 lux, 8 hrs. nightly, until the end of February. Right: Non-irradiated plants.

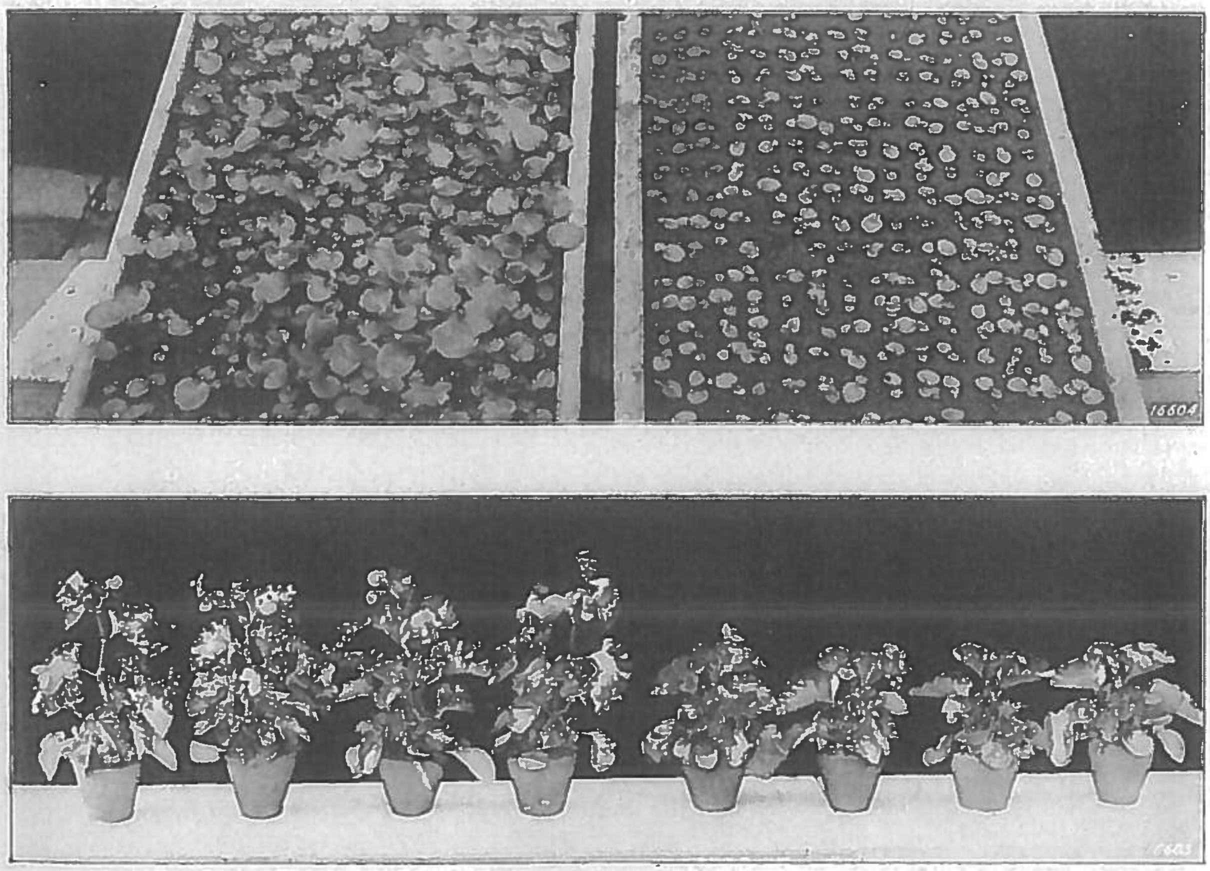

Fig. 6. Begonia gracilis luminosa. Sown November 3, 1934.
a) Picture taken on January 2, 1935. Left: Irradiated with neon light, approx. 600 lux, 10 p.m. to 6 a.m. nightly, from November 21. Right: Non-irradiated plants.
b) Picture taken on April 6, 1935, the same plants as shown in (a). Left: Irradiated till February 15, 1935. Right: Non-irradiated plants.
The second picture, which was taken seven weeks after the end of irradiation, shows very clearly the after-effects of irradiation.

modern types of tube are shown in *fig. 7*. A summary of the dimensions, applications and light outputs of these tubes is given in *Table I*.

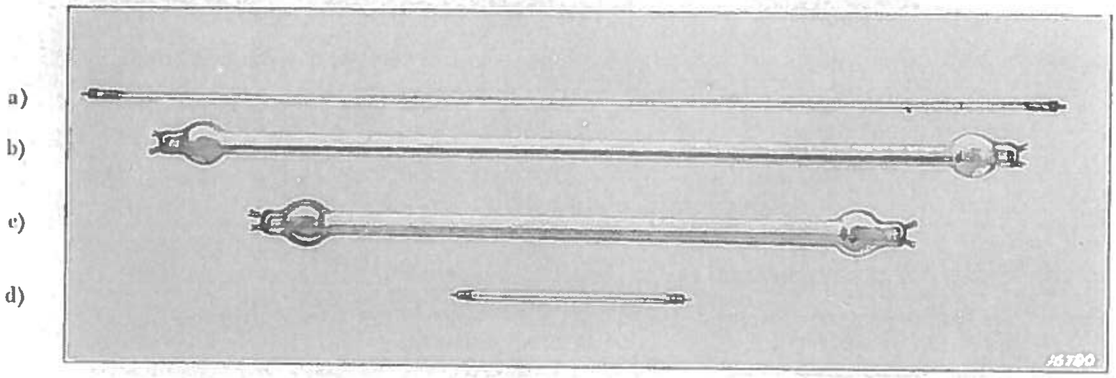

Fig. 7. Some early high-tension neon tubes (*a*) and various modern low-tension neon tubes (*b* to *d*). The electrical and illumination characteristics of these tubes are collated in Table I. Tube (*b*) emits practically 30 times as much light as (*a*) with approximately double the light yield; the small tube (*d*) gives almost four times the light obtained from (*a*).

The hot cathode is that component of the tube which ultimately determines the life of the tube, since the emitting substance (barium-strontium oxide) on the heated coil is steadily consumed. During the burning of the lamp the cathode suffers practically no disintegration at all and the light output of the tube remains uniform. Only after 2000 running hours does the consumption of the radiating substance become noticeable, the voltage-drop at the cathode increases, the cathode commences to be atomised, and in its neighbourhood a black deposit forms on the glass wall [5]), which adsorbs gas, as a result of which the cathode voltage-drop increases considerably until it becomes impossible to run the tube off the mains voltage and the tube must be replaced. The long life of 2000 running hours of the tube is due, *inter alia*, to the fact that in front of each cathode a plate is located (see fig. 7) which in the positive phase of the alternating voltage serves as anode and in this way protects the heated coil from excessive heating during the anode phase.

Circuit details and construction of plant irradiators

The neon tubes with hot cathodes are connected directly to 220 or 380 volts mains supply through a series-connected choke coil. In contrast to high-tension tubes special provision must be made here for starting up the tube, since the running voltage is too low to initiate the first electric discharge through the low-pressure neon gas. The extra-tension impulse which is obtained at the terminals of the series-connected choke on shorting the neon tube is utilised for this purpose. After the first discharge has taken place adequate residual ionisation is retained in the tube for re-ignition to be regularly obtained with a 50-cycle A.C. on reversing the polarity, even with a voltage which is too low for initiating the first discharge.

The circuit details of the large plant irradiators (types 4308, 4310 with tubes 4307, 4309) which have been designed for market growers, are shown in *fig. 8*. *T* is the heating transformer for the

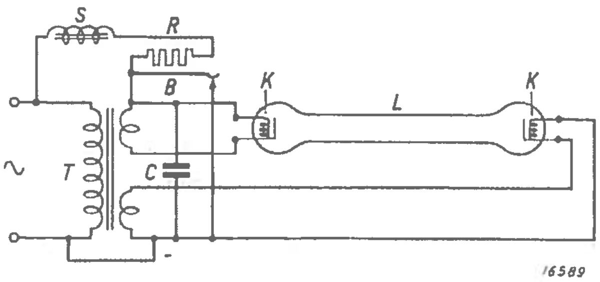

Fig. 8. Circuit details of the plant irradiator 4308 and 4310. The tube *L* is connected to the A.C. mains through a series-connected choking coil S. A bimetallic slow-acting relay *R* and *B* control signition. The cathodes *K* are heated through their own heating transformer *T*.

heated coils *K* which are run on 2 volts and 18 amps. *S* is the series choke coil. The heating coil *R* and the bimetallic strip *B* constitute a slow-acting relay, which connects up the initially-shorted tube *L* only after the coils *K* have become sufficiently heated. The tube is thus started up automatically by the slow-acting relay. If the first attempt at starting up fails owing to the phase of the supply being temporarily unfavourable at the instant the relay operates, the starting procedure is immediately repeated. The condenser *C* connected in parallel with the tube facilitates re-ignition, thus reducing

[5]) The black deposit is always restricted to the neighbourhood of the cathodes; the whole tube is never covered with a black deposit.

the mains voltage required and at the same time suppressing radio interference.

For small-scale operations and to meet the requirements of amateur horticulturists for conservatories and indoor use, a lower-power irradiator (rated for 90 watts) has been designed of which circuit details are given in *fig. 9*. By omitting the automatic starting device the circuit has been much simplified, whilst it has also been found possible to dispense with a heating current for the cathodes. When the cathodes have been once raised to the requisite temperature at the beginning of the discharge, they are kept suitably hot by the discharge itself. By introducing a special circuit the series choke coil is used as a heating transformer for heating the cathodes at the start of the discharge: After connecting the irradiator to the mains the

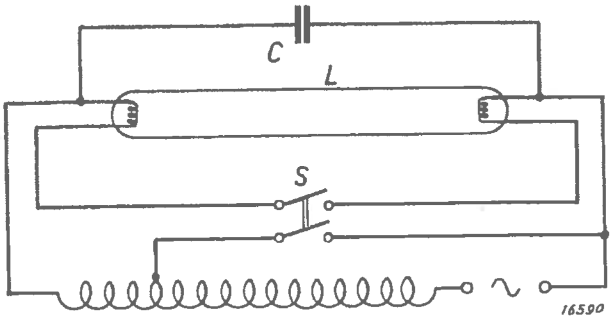

Fig. 9. Circuit diagram of the small plant irradiator 4312. By dispensing with the automatic ignition device the circuit has been much simplified; the choke coil also acts as a heating transformer.

two-pole switch *S* is pushed in, so that the choke now acts as an auto-transformer and the hot cathodes heat up. After releasing the switch the tube fires and the original circuit is re-established.

The light-yield of this small tube is 14 lumens per watt (taking into consideration all losses); it has a life of 1000 running hours.

Installation of irradiation units

The neon tubes are mounted in reflectors, which considerably increase the efficiency of irradiation. These reflectors are flat and fairly small, so as not to take up too much space in the usually low forcing and greenhouses and particularly so that they do not cast a wide shadow during the day. The live ends of the tube are protected in the reflectors. The large irradiation units 4308 and 4310 (see *fig. 10*) are connected up through cables to a watertight cast-iron box containing the transformer, choking coil and relay. In the case of the small irradiator 4312 the input unit (choke, condenser

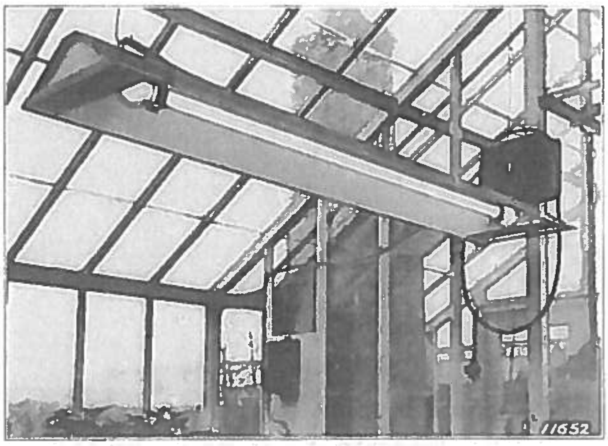

Fig. 10. The large plant irradiator 4310 installed for use. The input unit (*T*, *B*, *R*, *C* and *S* in fig. 8) is enclosed in the watertight cast-iron box on the right, to which the tubes mounted in the reflector are connected by a cable.

and switch) is incorporated with the tube in the radiator, thus making a very simple arrangement which can be directly connected to a 220-volt A.C. mains plug (*fig. 11*). With this unit an area of 10 sq. ft. can be adequately irradiated from a distance of 20 to 24 in.; the larger irradiator 4308 is sufficient for irradiating an area of about 100 sq. ft. The large units are suspended above the plants at a height of 3 to 5 ft. When suspending a series of irradiators in a forcing house a space equal to the length of the irradiator is usually left between consecutive units, this arrangement permitting an efficient and comparatively uniform irradiation of the plants.

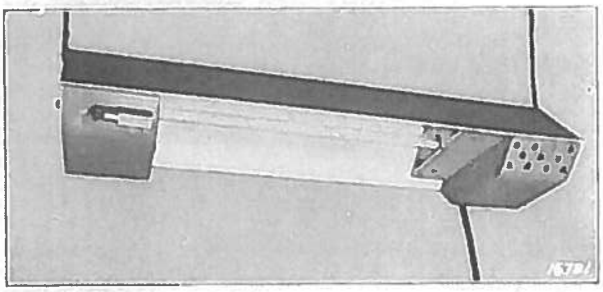

Fig. 11. The small plant irradiator 4312. The input unit is here incorporated with the tube in the reflector, thus giving a very simple arrangement.