Photomorphogenesis is concerned with the regulation of plant growth by visible radiant energy. The term is applied here only to those reversible photochemical reactions which are most actively excited at the red end of the visible spectrum and exert control of such diverse processes as seed and spore germination, seedling development and flowering. The kinetic similarity of these responses in regard to their action spectra, logarithmic response to the incident energy, low level of threshold energy required to induce the reaction, and the capacity of the induction process to be reversed or blocked by far-red energy, have led to the general conclusion that they are all controlled by the same photochemical mechanism and involve the same photoreceptor pigments. The spectral region of maximum effectiveness for induction has been shown to be in the red between 600 and 700 m\(\mu\) (2, 4, 9, 16, 17, 18, 19, 25) and the consequences of red induction can be prevented by subsequent or simultaneous irradiation with far-red between 700 and 750 m\(\mu\) (3, 6, 7, 10).

The action spectrum of the photocontrol of seedling development has been studied in relation to the following responses: a) inhibition of the first internode in Avena (1, 9, 20) and several other grasses (21); b) stimulation of the Avena coleoptile (1); c) stimulation of leaf growth in pea and bean (19, 15); d) inhibition of the hypocotyl of bean; and e) stimulation of epicotyl stem and leaf growth in bean (11, 12, 25). The action spectrum of seed germination and spore germination have shown similar general characteristics (4, 5, 16). The responses of the seedling organs thus far studied are directly proportional to the logarithm of the incident energy (12).

These different organs were all considered as potential assay systems for the action spectrum studies.

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ACTION SPECTRA OF PHOTOMORPHOGENIC INDUCTION AND ITS PHOTONOACTIVATION 1,2,3

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The Avena first internode is the classical organ which has been most extensively investigated, but its extreme sensitivity makes it difficult to handle and results often are not very uniform. The straight hypocotyl portion of the stem of the Black Valentine bean also is quite sensitive. In addition, the excited hypocotyl does not lend itself well to growth studies since the base tends to split. It also is relatively difficult to measure straight growth as compared with the measurement of a stem angle. The hypocotyl hook of bean is much less sensitive and, with a 20-hour light exposure, requires approximately 1000 times as much energy for threshold activity as the first internode of Avena. In view of these considerations, the hypocotyl hook was selected as the most suitable organ for the precise determination of the action spectrum of photomorphogenesis. Its sensitivity is sufficiently high for use with low intensity monochromatic sources and our experience with it has shown that it gives very reproducible results. It is large enough to be handled easily and the hook angle can be quickly read to the nearest 5 degrees.

MATERIALS AND METHODS

BIOLOGICAL MATERIALS: The same general techniques were used as previously described for the hypocotyl hook bioassay (11). Dry seeds of Phaseolus vulgaris, var. Black Valentine, sieved for uniform size, were germinated and grown in gravel beds subirrigated with tap water in complete darkness in a constant condition room maintained at 25°C and 75% relative humidity. At 6 days from seeding, the hooks were selected for a zero degree angle and arranged in a circle on moist filter paper in a 150-mm Petri dish, 20 hooks per dish. Manipulation of the hooks was done over a green safelight table with a second safelight mounted above the table. No measurable hook opening response to the safelight was observed with an exposure period of 1 hour (23). The experimental safelight exposure actually never exceeded 10 minutes and was usually much shorter. Each experiment was terminated 20 hours after excision with the reading.
of the hook angles, using a parallel-line grid protractor calibrated in 5-degree units.

Irradiation: The monochromatic irradiation system consisted of ten interference-filter monochromator units mounted on wood cabinets as previously described (22). The cabinets were arranged on a long table in a constant condition room. Each monochromator unit contained two Bausch & Lomb, 2-inch square interference filters in tandem, a dyed-gelatin filter of the Wratten type mounted in between, and a 10-cm aqueous filter. An additional aqueous filter of 2 cm of 30% copper sulfate solution was placed over the exit aperture of the monochromator unit when working in the green and blue in order to completely exclude all red energy that might leak around the filter system. When irradiating with the far-red, a dyed-gelatin supplemental filter was used to absorb the red-induction region shorter than 700 mμ. A spectral range from 365 to 800 mμ was covered in three series of experiments, with at least one wavelength station overlapping between contiguous series. The stations were 10 mμ apart through the red and far-red and approximately 20 mμ in the remaining portions of the spectrum.

The incident irradiances were adjusted to the proper value with a thermopile operating into a recording modulation amplifier. The thermopile was calibrated frequently against a Bureau of Standards standard lamp. Irradiances of 1 μw/cm² or higher, were balanced directly with the thermopile-amplifier system. Lower irradiances were obtained by first adjusting to an intensity of 1 μw/cm² and reducing by half-log factors with neutral density filters. Since dyed-gelatin neutral density filters are not spectrally neutral, especially at the ends of the visible spectrum, it was necessary to make further correction by adjusting the voltage on the incandescent lamp source or, in the case of the mercury arc, the resistance in series with the lamp (24). A photomultiplier detector was used to establish the proper ratio with neutral density filters. This method made it unnecessary to depend upon the nominal density values of the neutral filters or upon the spectral calibration of the photomultiplier tube in order to establish the correct values of irradiance.

The photoreversal series required an induction treatment before subjecting the hooks to the monochromatic irradiation. This was supplied in a separate cabinet containing a red gelatin filter and a bank of 15-watt special fluorescent lamps containing a magnesium arsenite phosphor, which was supplied by the General Electric Company. These lamps emit most of their energy in the red, with a spectral peak at about 660 mμ and relatively little energy longer than 700 mμ. This source had a wavelength band of 600 to 700 mμ and gave an irradiance of 300 μw/cm². The induction exposure time required for an incident energy of 250 mj/cm² was 14 minutes.

Controls: Two controls were used in all induction experiments and three in the inactivation series. For induction, there was a dark control and a standard red control which received 20 hours continuously of 0.1 μw/cm² or a total incident energy of 7.2 mj/cm². In addition to these two, a third control of 14 minutes red, totaling 250 mj/cm² was used for all inactivation experiments. At the end of the 20-hour period, the average dark control angle of opening was zero degrees, the range of the standard red control was 67° to 73°, and for the 14-minute red control was approximately 50°. A deviation from these results was considered as an indication that the hooks were not responding normally. This seldom occurred, but occasionally, because of variations in cultural conditions or failure of the irradiation equipment, the controls did not give standard values; the whole series of results was then rejected.

A separate cabinet and source system was used for the standard red irradiation. The source was a 120-volt incandescent lamp operating at 80 watts or 67% of rated voltage. At this low voltage, an incandescent lamp rated at 1000 hours has over 100 times the life expectancy of a similar lamp operating under normal conditions (24). Consequently, the intensity of the source changed very little with time and a single adjustment of the standard irradiance was sufficient for at least one year of almost continuous use. The filters for the standard cabinet consisted of 10 cm of 1% hydrated copper sulfate and a red dyed-gelatin filter which, together, yielded a transmission band of approximately 625 to 700 mμ. The source used in the 14-minute red control was similar to that described previously for the reversal series.

In both the induction and inactivation (reversal) experiments, the irradiation periods were kept short as compared to the total experimental time of 20 hours. Where growth is used as the criterion of a photoreaction, the response is the result of many relatively slow thermochemical (dark) reactions which are altered in rate by the photoreaction. Kinetic separation of the two groups of processes can be effected only if the photoreaction time is small compared to the dark time. Also, the monochromatic irradiation involved high-powered lamp equipment spaced over a considerable distance in a constant condition room, thus making it difficult to ensure exactly the same environment for all of the wavelength stations. By making the irradiation time less than three hours, it was convenient to remove the hooks from the monochromator cabinets to a single dark cabinet for the remaining development period of 17 hours.

The irradiation time was a constant value for each group of experiments. It was 2.78 hours for the induction series. For the inactivation series, 14 minutes was used for induction and 30 minutes for inactivation. The induction reaction of various photomorphogenic seedling responses, including that of the opening of the hook (11), is proportional to the logarithm of the incident energy. Reciprocity does not hold for

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4 One microwatt (μw) in MKS units is equivalent to 10 erg/sec in cgs units; the microjoule (μJ) is equivalent to 10 ergs.
these processes over long exposure periods. A continuous irradiation of 20 hours (10 \( \mu \)J/cm\(^2\) threshold) is more effective than a 2.78-hour exposure (30 \( \mu \)J/cm\(^2\) threshold) for the same total incident energy. While the photoreversal process, calculated as an inactivation factor, is a linear function of irradiance for incident energies yielding up to about 90% reversal, it does not follow reciprocity, i.e., the degree of reversibility for a constant value of energy increases with time up to between 1 and 2 hours (13). However, almost complete reversibility can be obtained by the end of the first 30 minutes. Because of the logarithmic function in induction and lack of reciprocity of both of these reactions, results with different incident energies, therefore, are comparable only if all irradiation times are kept constant.

With an interference-filter monochromator system it is possible to establish either a constant incident energy or quantum intensity spectrum for each series. Since a quantum intensity spectrum would have required an energy correction factor at each wavelength, it was more convenient to use a constant incident energy for each wavelength series and then convert to quantum values for the calculation of the action spectrum.

**TREATMENT SCHEDULE:** The complete sequence of manipulations for obtaining the induction action spectrum were: 1) Selection and excision of uniform hypocotyl hooks and arrangement in a Petri dish, using a green safelight. 2) Exposure to the appropriate wavelength of monochromatic radiant energy in a cabinet for 2.78 hours (10,000 seconds), this time yielding an incident energy of 10 mj/cm\(^2\) or 100,000 ergs/cm\(^2\) for an incident irradiance of 1 \( \mu \)W/cm\(^2\). The incident energies were adjusted on a logarithm scale of 0.5 log units or a ratio of about 0.3 between energy steps and were 0.1, 0.3, 1.0, 3.0, 10.0, 30.0 and 100 mj/cm\(^2\). 3) Transfer of all hooks to a dark cabinet for a development period of approximately 17 hours to make a total time from excision of 20 hours. 4) Reading of the hook angles with a protractor.

The sequence of manipulations for obtaining the photoinactivation or reversal action spectrum were: 1) Excision of the hooks as above. 2) Induction with energy from a red fluorescent lamp (600 to 700 m\( \mu \)) for 14 minutes, which yielded an incident energy of 250 mj/cm\(^2\). 3) Transfer for photoinactivation exposure to a monochromator cabinet for a 30-minute period at a specified wavelength and irradiance. 4)

---

**FIG. 1.** Equal energy curves for photomorphogenic induction, hook angle vs wavelength, for incident energies of 0.1 to 30 mj/cm\(^2\). The energy was applied over a period of 2.78 hrs (10,000 sec) at 0.01 to 3.0 \( \mu \)W/cm\(^2\). Each curve represents a response to wavelength at one energy level and each point represents the average of 4 to 6 replicates of 20 hooks each.

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Fig. 2. Linear regression lines of induction, hook angle vs incident energy. Each line represents one wavelength. These graphs were plotted from the same data as in figure 1 for determining the energy required for specified response values. The horizontal dashed lines at the 8° and 25° levels were used for calculation of the induction action spectrum. The energy scales have been shifted one step to the right for each regression line to prevent superposition for the different wavelengths; each curve is represented by a separate scale.
Development in the dark for approximately 19 hours to total a 20-hour period from excision. 5) Reading of the hook angles.

RESULTS

Induction Spectrum: The data for the angles of hook opening were averaged for the various replicates (a minimum of 4 for each point) and a family of equal energy curves plotted as a function of hook angle vs wavelength, figure 1. These curves do not have the same shape as the true action spectrum because they involve equal incident energy instead of equal response and the logarithmic character of the response tends to reduce the relative magnitudes, although not the positions of the peaks.

The data of figure 1 are replotted in figure 2 as a family of wavelength curves of hook angle vs log energy. These curves are straight lines for hook angles above about 5°. In order to prevent the superposition of the curves, each line and its respective energy scale are shifted one unit to the right. The curves were calculated as regression lines by the method of least squares. The shorter wavelengths from 365 to 578 mυ are presented in figure 2 A and the longer wavelengths from 578 to 720 mυ in figure 2 B.

From the equations of the angle vs log energy curves, the incident quanta required at each wavelength to produce an opening angle of 8° and of 25° were calculated. An angle of 8° was the largest that could be obtained throughout most of the spectrum and required a minimum of extrapolation; 25° was about the mid-range of the angles obtainable in the red with incident energies up to 10 mj/cm². The 25° angles were therefore calculated only for the red end of the spectrum since it was not possible to obtain large angular openings in the shorter wavelengths. The action spectra plotted in figure 3 are given as relative quantum responsivity. By multiplying the ordinant by a factor of 0.17, the values may be converted to absolute quantum responsivity in degrees/(nano-einstein/cm²). The nano-einstein is used here because it yields conveniently-sized values. It is 10⁻⁹ (milli-micro) einstein or mole of quanta. The factor 2.8×10⁻¹⁶ converts the data to degrees/(quanta/cm²).

The following summarizes the calculations and formulas used for the induction action spectrum:

a. Calculation of the angle vs log-energy regression lines in the form:

\[ \theta = m \log E + b \]

where, \( \theta \) is the angle of the hook, in degrees; \( m \) is the slope parameter; \( E \) is incident energy, mj/cm²; and \( b \) is the ordinate intercept parameter.

Fig. 3. Action spectrum for photomorphogenic induction. The ordinant is relative quantum responsivity calculated for an 8° or 25° response per unit incident quanta. The ordinant values multiplied by the factor 0.17 convert relative responsivity to absolute responsivity in degrees per nano-einstein/cm². The factor 2.8×10⁻¹⁶ converts to degrees per quanta/cm². Dashed curve is for the relative chlorophyll concentration obtained in the hook tissue by a 2.78-hour exposure.
b. Analytical or graphical determination of the energy, E, required to produce a specified response angle, \( \theta' \):

\[
E = \text{antilog} \left( \frac{\theta' - b}{m} \right)
\]

c. Conversion of energy units from E (mj/cm\(^2\)) to n (nano-einstein/cm\(^2\)):

\[
(3) \quad n = \frac{\lambda E}{Nhc} = \frac{\lambda E}{120} = 8.33 \times 10^{-3} \lambda E
\]

where, \( \lambda \) is wavelength, m\( \mu \); N is Avogadro's number, 6.025 \times 10^{14} \text{molecules/nano-mole}; h is Planck's constant, 6.625 \times 10^{-34} \text{mj \cdot sec}; and e is the speed of light, 3.00 \times 10^8 \text{m} / \text{sec}.

d. Introducing n into the regression line formula, (1) becomes,

\[
(4) \quad \theta' = m (\log n + \log 120/\lambda) + b
\]

Thus, the quantum energy curves plotted on a logarithmic scale have the same slope as the energy curves of figure 2, but different intercepts.

e. Calculation of quantum responsivity, R, degrees/(nano-einstein/cm\(^2\)), for hook angles in degrees, \( \theta' \), of 8\(^\circ\) or 25\(^\circ\).

\[
(5) \quad R = \frac{\theta'}{n'} = \frac{120 \theta' / \lambda E}{\lambda E'}
\]

When the response is proportional to the logarithm of the stimulus, various criteria can be set up for the responsivity of the organ. The responsivity can be expressed as the slope of the log energy-response curve (m), as the absolute value of the intercept parameter (b), as a threshold value which would involve the intercept on the energy rather than the angular response axis (\(-b/m\)), or as the ratio of response to incident energy when evaluated at a specified response level (R). The last form of expression is used here in calculating the action spectrum curves of figures 3 and 6. However, certain of the other modes of expression are useful in clarifying the probability of existence of minor peaks and other details of the spectrum. Therefore, the slope, m, is plotted in figure 8.

When it was found that the induction action spectrum had a strong peak at 660 m\( \mu \), the question arose as to whether the photoactivation of protochlorophyll and its conversion to chlorophyll a might be involved. To test this possibility, the position of the peak of the action spectrum of chlorophyll synthesis was determined by treating hooks in the same manner as for the photomorphogenic induction action spectrum and immediately extracting in acetone. The hooks were irradiated for 2.75 hours, and then, instead of allowing a development period in the dark, the tissue was macerated and assayed for chlorophyll a as described previously (12). The relative concentration of chlorophyll a formed in the hook at several wavelengths in the red are plotted in figure 3 as the dashed curve. The protochlorophyll conversion peak occurred at 650 m\( \mu \) in accordance with data published by Frank (8) and by Koski et al (14).

**PHOTOINACTIVATION:** The inactivation spectrum was calculated in essentially the same manner as the induction action spectrum. The inactivation factor, B, was calculated by the following formula:

\[
(\theta) \quad B = \frac{\theta_1 - \theta}{\theta_1}
\]

where, \( \theta_1 \) is the hook angle with the induction treatment of 250 mj/cm\(^2\) applied alone for 14 minutes (50\(^\circ\) angle) and \( \theta \) is the angle obtained after inactivation. A factor of 1.0 indicates 100% inactivation (\( \theta = 0 \)) while a factor of zero implies that no inactivation occurred and \( \theta_1 = \theta \). A negative value is obtained when the second irradiation increases rather than decreases the effect of the induction treatment.

The inactivation factor obtained from formula (\( \theta \)) is plotted against wavelength in figure 4 for a series of energies at 0, 2.5, 5.0 and 10 mj/cm\(^2\). The regression curves for each wavelength are presented in figure 5 for the range of 700 to 760 m\( \mu \). Up to about 85% inactivation, the response is proportional to energy. The energy scales have been shifted two units for each curve in order to prevent superposition. The quantum inactivation, B, in per nano-einstein/cm\(^2\) for 50% inactivation was obtained from the formula:

\[
(7) \quad B = 120 B''/\lambda E''
\]

---

**Fig. 4.** Equal energy curves for photoinactivation. Data are plotted as inactivation factor vs wavelength at four values of incident energy applied over a 30-min period. Hooks were induced with a red (600 to 700 m\( \mu \)) exposure of 250 mj/cm\(^2\) (300 \( \mu \)W/cm\(^2\) for 14 min) and then inactivated with the energies and wavelengths shown. A factor of 1.0 indicates 100% reversal; negative values indicate that the reversal treatment increased the hook opening.
where $E''$ is the inactivation energy required to give a factor $B''$ of 0.5.

The quantum inactivation curve is graphed as relative values in figure 6. By multiplying by the factor $1.3 \times 10^{-4}$, it is possible to convert to absolute units of inactivation, per nano-einstein/cm$^2$.

**DISCUSSION**

Induction: The family of curves for wavelength vs hook angle, as plotted on an equal energy basis in figure 1, shows that the induction response has certain spectral features which consistently appear at all energy levels. The peak at 660 m$\mu$ is the most prominent feature and shoulders occur at slightly shorter and longer wavelengths. There is one shoulder in the vicinity of 560 m$\mu$ and a second around 620. The long-wavelength shoulder is in the general region of 680 to 700 m$\mu$. The shoulders are most prominently indicated when the slopes of the energy-angle curves are plotted (fig 8). There are two minor peaks in the shorter wavelengths, one between 500 and 520 m$\mu$, and one in the vicinity of 400. All of these features appear in the calculated action spectrum curves of figure 3. Using broad band filters, Weintraub and Price (21) obtained a shoulder in the vicinity of 580 m$\mu$ for Avena mesocotyl. The action spectrum for fern spore germination secured by Mohr (16) also shows a shoulder in the vicinity of 600 m$\mu$. It is concluded that this shoulder is evidence of a second minor peak in the pigment contributing to the induction.

The chlorophyll synthesis curve of figure 3 strongly supports the conclusion that protochlorophyll is not directly involved in the photoactivation of the induction mechanism. Since chlorophyll concentration was measured in the hook tissue with the same irradiance and times used for obtaining the induction curves, the two peaks would be expected to coincide if the two processes were being initiated by the same pigment. Further evidence for this conclusion is obtained from data on the effect of far-red energy, beyond the limit for chlorophyll synthesis, on the induction of photomorphogenic responses in the bean seedling (25). It was found possible, by using high energies in the far-red beyond 700 m$\mu$, to induce a significant photomorphogenic reaction without any detectable synthesis of chlorophyll.

While the action spectrum peak of the induction process is at 660 m$\mu$, the shape of the curve probably is strongly influenced by interaction with the inactivation process. The two reactions must compete and they undoubtedly attain various equilibria in the range of about 620 to at least 720 m$\mu$. Therefore, it is quite possible that the absorption peak of the induction pigment is at a somewhat longer wavelength than 660 m$\mu$, possibly between 660 to 680 m$\mu$.

![Figure 5](https://www.plantphysiol.org/downloadable/figs/psp/00459/psp00459f05.jpg)

**Fig. 5.** Photoinactivation regression lines, inactivation factor vs incident energy. Energy scales are shifted two steps to the right for each curve to prevent superposition. Curves for the 710, 720 and 730 m$\mu$ wavelengths are extended to 15 mj/cm$^2$; each curve is extrapolated to zero energy by a dashed line.
Fig. 6. Photoinactivation (reversal) action spectrum based on a factor of 0.5. Relative quantum responsivity may be converted to absolute values by multiplying the ordinate by $1.3 \times 10^{-4}$ per nano-einstein/cm² or by $2.2 \times 10^{-19}$ per quantum/cm². For comparison, the $8^\circ$ induction action spectrum is included as the dashed curve.

The non-linearity of the induction process is evident from figure 9, in which the incident energy is plotted against hook angle. The log plots of figure 2 show that the response is closely proportional to the log of the incident energy, especially over the range of 578 to 660 mμ. At shorter and longer wavelengths, the linear nature of the log function is not so consistent. The points at 405, 420, 460 and 560 show evidence of saturation, even when plotted on a log scale. This type of saturation or tendency for the curve to break has been shown for the blue in regard to the development of various organs of the whole seedling (12). The tendency to saturate in the shorter wavelengths may very likely be due to photochemical interactions with the yellow pigments and may be a very indirect effect.

Weintraub and McAlister (20), Weintraub and Price (21) in Avena seedlings, and Parker et al (19) in pea, have shown evidence that the log energy-response curves are straight lines which break at some high value of incident energy and assume a new slope, which is again a straight line. We have no evidence of this type of break, either for the whole bean seedling (12) or for the hook response. Either we have not used sufficiently high intensities in our experiments or the break in an artifact at high intensities. The results of Klein et al (11) have shown that incident energies over a million-fold range fall on the same straight line in regard to hypocotyl straight growth inhibition. The curve breaks only when the shorter wavelengths are used.

Inactivation: The equal-energy inactivation curves of figure 4 and the calculated action spectrum of figure 6 show two major peaks at 710 and 730 mμ and a minor one at 640, with a slight peak at about 400 mμ in the blue. When plotted on an equal energy basis, the 710 and 730 peaks shift in relative magnitude with incident energy. At 2.5 and 5.0 mj/cm², the 710 peak is dominant, whereas at 7.5 and 10 mj/cm², the 730 peak is dominant. The relative values of these peaks were measured and their ratio calculated in the range of 2.5 to 40 mj/cm² and the data plotted in figure 7. When this curve is extrapolated to zero energy, the ratio of the 710 and 730 peaks, as evaluated in terms of inactivation factor, extrapolate to about 1.3. This makes it appear that the 710 mμ peak may be the dominant one, and, as the incident energy is increased, it is suppressed by interaction with the induction process which extends into this region. It also is likely that the minor 640 peak may not be a true peak at all, but may result from suppression at 660 mμ by the induction process and that the absorption spectrum of the inactivation pigment actually rises slowly from about 620 mμ to a maximum at 710 mμ. It seems very possible that the absorption spectra of the photoinduction and photore-
versal pigments may be quite similar in shape, with the latter shifted 20 to 30 m\(\mu\) to the longer red wavelengths.

**SUMMARY**

The action spectrum of the induction of photomorphogenesis in the bean hypocotyl hook shows certain features which are consistent with the red, far-red groups of reactions in general. The induction response in terms of hook angle vs log of incident energy is linear over the range of at least 0.1 to 30 mj/cm\(^2\) for the wavelengths of 578 to 660 m\(\mu\). At longer and shorter wavelengths, the linearity is not so clear. The action spectrum shows a sharp major peak at 660 m\(\mu\), with evidence of two shoulders in the vicinity of 560 and 620 m\(\mu\) and possibly a third shoulder at 700 m\(\mu\). In the shorter wavelengths, two minor peaks appear in the vicinity of 400 and 500 m\(\mu\). Because of the close proximity to the peak of inactivation, it is very possible that interaction between the two has shifted the apparent induction peak somewhat toward the shorter wavelengths and that the actual absorption peak of the absorbing pigment is in the range of 660 to 680 m\(\mu\).

**Fig. 7** (left). Ratio of the 710 and 730 m\(\mu\) inactivation factors. The ratio, B\(_{710}\)/B\(_{730}\), is plotted against energy.

**Fig. 8** (right). Regression line-slope values vs wavelength for the induction and inactivation processes. These are the slope constants, m and m', respectively, derived from the regression line formulas.

**Fig. 9.** Energy-response curves for the induction and inactivation processes plotted on a linear energy scale.
The reversal response is a linear function of incident energy up to 85% reversal. Beyond that, the curve shows sharp saturation at approximately 90%. The action spectrum for the inactivation process has two major peaks at 710 and 730 mμ, with a minor one at 640. The ratio of the 710 to 730 mμ peaks at various incident energies shows that, at low energies, the 710 peak is dominant and at high energies, the 730 peak is dominant. It is considered very likely that 710 is the principal peak in the absorption spectrum of the photoactivated pigment. The data indicate that the absorption spectra of the pigments responsible for induction and reversal in photomorphogenesis may be similar in shape, with the latter shifted 20 to 30 mμ to the longer red wavelengths.

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Literature Cited


