Bio Factsheet

Number 48

Tackling Exam Questions: Plant Growth Substances

The amount of information which students need on this topic varies significantly between different A Level syllabuses. This Factsheet summarises:

1. Those aspects which are common to most syllabuses
2. The topics which most often feature in exam questions

Generally there are 6 common types of exam question:

1. Definitions – these are given in Table 1
2. Analysis of experiments – usually these focus on auxins
3. Graph questions on auxins
4. Photoperiodism
5. Economic aspects of plant growth substances
6. Synoptic essay-style questions on plant growth substances

Table 1. Common definitions

Growth	Definition
Tropism	Growth movement of part of a plant where the direction of response is determined by the direction of stimulus
Nastic movement	Plant movement where direction of response is predetermined and is not determined by direction of stimulus e.g. closure of Venus fly trap. Movement often occurs because of change in turgidity.
Tactic response	Movement of whole organism in response to unidirectional stimulus.

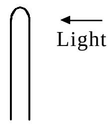
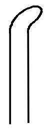
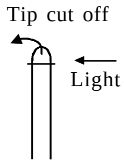
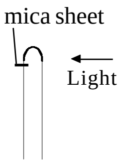
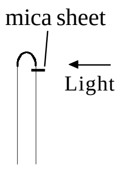
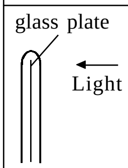
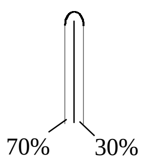
2. Analysis of experiments

A tropism is a growth movement of part of a plant in response to a directional stimulus. Phototropism is the growth of part of a plant in response to a light stimulus.

Shoots show **positive phototropism** i.e. they grow towards the light. Most investigations use oat or grass seedlings. The most commonly examined investigations are summarised in Fig 1.

> **How does auxin cause elongation?**
> 1. Auxin causes cell to deposit H^+ ions into their cell walls.
> 2. pH decreases
> 3. This provides optimum conditions for enzymes which break the cross links between adjacent cellulose microfibrils.
> 4. Wall is weakened
> 5. Water enters, turgidity increases, causing stretching and elongation At the same time, auxin seems to increase transcription, hence rate of protein synthesis and accelerate growth.

Fig 1. Investigations involving plant growth substances

Investigation	Result	Significance
	 Bends toward light	Shoot is positively phototropic
	 No bending	Tip detects light or produces a chemical or other type of signal which causes bending.
	 No bending	Signal from tip must be chemical because it is unable to pass through mica. Cannot be electrical because this would pass through.
	 Bends toward light	Chemical signal must pass down the side furthest away from light.
		After illumination, amount of auxin on either side of glass plate is measured. Light causes auxin to move away from illuminated side.

3. Graph questions on auxins

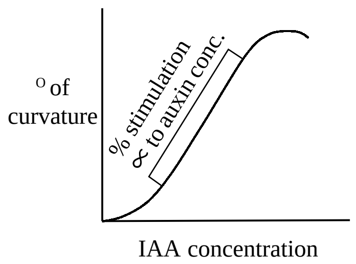
The first auxin to be discovered was IAA (indoleacetic acid). Auxins are synthesised in regions of rapidly dividing cells, which are known as **meristems**. Auxin may be actively transported from cell to cell or may be transported in the phloem sap.

Auxin, produced by cells at the tip of the shoot, causes cell elongation. Because auxin accumulates on the non-illuminated side of the shoot, it is these cells which elongate the most. This causes the shoot to bend toward the light. In turn, this provides the plant with maximum light, maximising the rate of photosynthesis, hence growth.

> ***Exam Hint*** *- There is no point in trying to remember the significance of every plant growth substance experiment. Instead, concentrate on understanding the processes involved. Many exam questions then ask you to comment on the* ***biological significance*** *of the plants response - in other words, what advantage do these movements give the plant?*

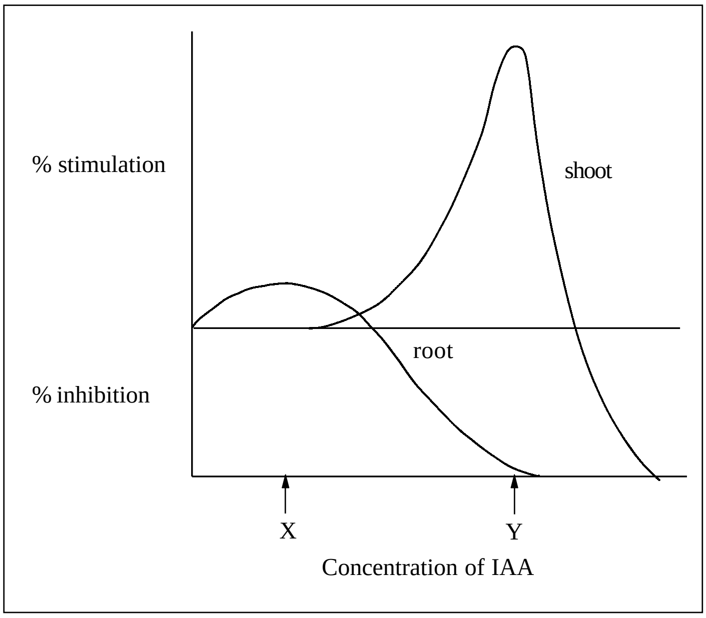
Bioassay
A bioassay is a technique for measuring the concentration of a substance by measuring its biological effect. In shoots, auxin causes cell elongation. The degree of cell elongation is proportional to auxin concentration (Fig 2).

Fig 2. The effect of IAA on stem curvature



This relationship can be used to estimate the concentration of auxin in, for example, a piece of shoot. If the sample is placed on one edge of a decapitated coleoptile the auxin which the shoot contains will diffuse into the coleoptile and cause bending. The degree of bending can be measured and compared with the standard curve (Fig 2). The degree of curvature can then be used to indicate the auxin concentration.

Fig 3. Effect of adding auxin to shoot and root sections



At the very low auxin concentrations which causes root growth stimulation (X) there is no effect on shoot growth. At the very high auxin concentrations where shoot growth is maximally stimulated (Y), root growth is strongly inhibited. Since auxin is produced in the shoot tip, high concentrations occur there. The auxin then has to be transported to the roots and much smaller concentrations occur there. Thus, the concentration of auxin in the shoot and root is just what is required to stimulate maximum shoot and root growth.

Geotropism
Geotropism is a plant growth response to the stimulus of gravity. Shoots are negatively geotropic i.e. they grow in opposition to gravity. Roots are positively geotropic.

When a seedling is suspended and rotated in an instrument known as a **Klinostat** - which exposes all parts of a seedling to equal gravitational stimulation - both the shoot and root grow horizontally. ABA is the key substance in bringing about the geotropic response. ABA accumulates on the downward side of roots where it inhibits cell elongation. Thus, the cells on the top side of the root elongate more than the cells on the downward side, thus, the root bends downward.

Plant roots detect gravity using organelles called statoliths. Statoliths are large amyloplasts. The exact mechanism of how statoliths allow a plant to detect and respond to gravity is unclear. Fig 3, which shows the effect of just auxin on shoot and root stimulation comes up frequently on exam papers.

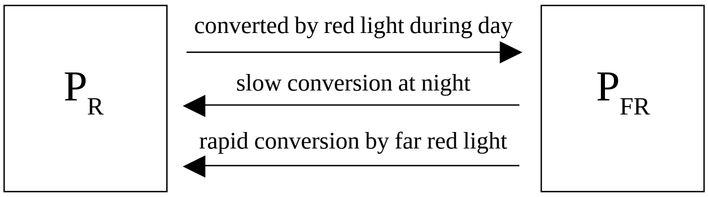
4. Photoperiodism
The phototperiod - length of daylight period - is detected by a leaf pigment called phytochrome. Phytochrome is not a plant growth substance but the plant's response to changes in photoperiod is brought about by growth substances, hence it is included in this Factsheet.

Phytochrome is therefore a photoreceptive pigment in flowering plants. By detecting the photoperiod, processes such as flowering, fruit formation, ripening etc. can be timed to coincide with the most favourable time of the year.

In terms of photoperiodism, there are 3 types of plant:
- Short Day (SD)
- Neutral Day (ND)
- Long Day (LD)

Phytochrome exists in two interchangeable forms - an inactive form P_R, so called because it absorbs red light of wavelength 660nm and an active form P_{FR}, so called because it absorbs far red light of wavelength 730nm.

Sunlight contains more red light than far red light so during the day the net effect is that P_R absorbs red light and is converted into P_{FR}. During the night, P_{FR} is slowly converted back into P_R. However, P_{FR} is rapidly converted into P_R by far red light (730nm)



Thus, as the photoperiod changes, e.g. in winter in the northern hemisphere as days get shorter, the balance between P_R and P_{FR} changes. As winter approaches, days shorten, nights get longer and the amount of P_R increases. The build-up of P_R and the decline in P_{FR} activates hormones which, for example, in chrysanthemums initiates flowering.

Thus, short day (SD) plants need a long period of continuous darkness in order to flower. This enables most or all of the P_{FR} to be converted back to P_R. In other words, it is P_{FR} which **inhibits** flowering in short day plants. If a single flash of red light is given to short day plants during their long nights some of the P_R will be converted to P_{FR} and the plant will not flower. Long day (LD) plants need a short period of continuous darkness in order to flower.

Thus, whilst the classification of plants into SD, DN and LD is still accepted, it is not actually the length of the day which is critical to processes such as flowering - it is the length of the dark period.

Occasionally, questions on phytochrome will ask 'How do we know hormones or growth substances are involved in the photoperiodic response'? There are two main types of evidence:

1. A plant which has been exposed to the 'wrong' photoperiod will not flower. However, if a single leaf from a different plant of the same species, which has been held in the correct photoperiod is grafted on to the plant, after a few days the entire plant will flower. The signal from the leaf must have spread throughout the entire plant.

2. The simple fact that there is a time delay between exposure to correct photoperiod and flowering indicates that the signal is only gradually transmitted and plant-growth substances would do just this.

5. Economic aspects
The most important economic and commercial aspects of plant growth substances are summarised in Table 2.

Table 2. Economic/Commercial use of Plant Growth Substances

Substance	Application
Auxin	1. Rooting powder - cut stems which are dipped into auxin powder develop adventitious roots. 2. Selective weedkiller – 2,4-D is a synthetic auxin which over-stimulates growth of broadleaved weeds, exhausting food reserves, leading to death. It has no effect on monocots. 3. Inhibition of sprouting of potatoes - increases storage time 4. Prevention of abscission - delays fruit drop in orchards 5. Stimulation of seedless fruit (parthenocarpy) 6. Nutrient in nutrient agar e.g. for micropropagation.
Gibberellins	1. Stimulation of germination of barley grains during malting stage of brewing. 2. Stimulation of growth of dwarf plants 3. Stimulation of fruit growth
Cytokinins	1. Used with auxin as a growth stimulant to produce calluses in micro-propagation.
Abscisic Acid	1. Maintenance of seed or vegetative organ dormancy - allows seeds or e.g. potatoes, to be stored for longer. 2. Stimulation of fruit drop, e.g. in orchards
Ethene	1. Promotes ripening. Bananas are picked when green, ensuring that they do not over-ripen during transport/shipping. Ethene then rapidly induces ripening. 2. Stimulation of fruit drop.

6. Synoptic essay style questions
Plant growth substances have a very wide range of effects in plants. Synoptic essay questions which ask you to describe the effects are usually simple. However, you need to take an organised approach and plan your response. There are 2 main approaches:

1. Describe each growth substance separately
2. Choose a type of growth substance e.g. root growth/flowering/ senescence and then describe which substances are involved.

Different students prefer different approaches, but 1. is the most common. Table 3 summarises the major roles and interactions of each type of plant growth substance.

Table 3. Effect of plant growth substances

Substance	Effect
Auxin	1. Brings about phototropic response 2. Stimulates cell division in meristematic tissue 3. Causes elongation 4. With ABA, brings about geotropic response - low auxin increases root growth and vice versa 5. Parthencorpy - add auxin to unpollinated stigma, ovary → fruit 6. Increases production of adventitious roots from cut stems 7. Delays abscission - leaf fall 8. Delays fruit drop 9. With sucrose 'stimulates' formation of vascular tissue in early germination 10. Apical dominance inhibits formation of side branches from lateral buds
Gibberellin	1. Causes rapid growth in dwarf varieties increases internodal length by enhancing effects of auxin i.e. increases cell elongation and increases cell division of meristematic tissues 2. Stimulates pathenocarpy 3. Can overcome need for cold period if added to seed so they germinate without remaining dormant through cold temperatures 4. Embryo in seed makes own gibberellins which triggers amylase secretion in aleurone layer around endosperm 5. Stimulates flowering in long-day plants 6. Stimulates leaf expansion
Cytokinin	1. Stimulates cell division so affects fruit development 2. Keeps leaves green and delays abscission 3. Cytokinin and auxin cause differentiation of undifferentiation cells - stem and roots develop. Just auxin roots develop, just cytokinin shoots develop 4. Stimulates growth of lateral buds 5. With gibberellins breaks seed dormancy
Abscisic Acid (ABA)	1. Stops growth of roots and shoots 2. Stops buds and seeds growing 3. Generally opposes gibberellins 4. Stimulates abscission
Ethene	1. Prevents elongation 2. Stimulates radicle growth 3. Unfolds hooks of developing leaves 4. Causes senescence of flowers after pollination and speeds up fruiting. Used commercially to speed up fruiting of last tomatoes in greenhouse

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