Plant Hormones and Applications

Like animals, plants use hormones to regulate their growth and development. Plant hormones (**phytohormones**) are organic compounds produced in one part of the plant and transported to another part, where they produce a growth response. Hormones are effective in extremely small amounts. There are five groups of phytohormones: **auxins** (indolacetic acid or IAA), **cytokinins**, **gibberellins**, **ethene**, and **abscisic acid** (ABA). Together they control growth and development of the plant at various stages. Synthetic analogues of IAA have been produced for commercial use and are applied as growth promoters in rooting powders, and as inducers for fruit production. Some analogues (e.g. 2-4-5-T) even act as growth inhibitors and are used as selective herbicides.

Site of Hormone Production

YOUNG LEAVES AND BUDS:

Auxin (IAA)
- Promotes growth in stem length
- Promotes cell enlargement and differentiation in cambium (growth of secondary vascular tissues)
- Responsible for **apical dominance**
- Delays onset of senescence and leaf fall

Gibberellins
- Delay onset of senescence and leaf fall
- Promote elongation in the region just below the shoot tip (subapical region)
- Promote secondary growth (with auxins)

EMBRYO WITHIN SEED

Gibberellins
- Break dormancy in seeds and buds
- Mobilise food stores during germination

DEVELOPING FRUIT

Cytokinins
- Essential for growth of young fruit

RIPE FRUIT

Ethene (ethylene)
- Induces fruit ripening

LEAF CHLOROPLASTS:

Abscisic acid (ABA)
- Growth inhibitor
- Made in response to water stress; acts on guard cells to promote closing of stomata
- Promotes seed dormancy

OLD LEAVES

Ethene (ethylene)
- Promotes leaf fall through the development of the abscission zone

Abscisic acid (ABA)
- Growth inhibitor, promotes seed dormancy

ROOT TIPS

Cytokinins
- Promote cell division
- Keep the shoot and root growth in balance
- Produced in the root tips and travel to the shoots and leaves in the transpiration stream

Auxin (IAA)
- Promotes growth in stem length
- Controls cell enlargement and differentiation

1. Describe one major effect of each of the hormones below, explaining its role in the plant life cycle:

(a) Gibberellins:

(b) Cytokinins:

(c) Ethene:

(d) Abscisic acid:

2. Describe the role of auxin (IAA) in each of the following plant growth processes:

(a) Apical dominance:

(b) Stem growth:

(c) Secondary growth:

3. Explain why pruning (removing the central leader) induces bushy growth in plants:

4. Describe how a horticulturist could use hormones to regulate the timing of the following life cycle events:

(a) To promote root development in plant cuttings:

(b) To induce ripening in fruit:

(c) To promote seed germination:

(d) To encourage seed dormancy prior to storage:

5. Identify the phytohormones predominating in the leaves of:

(a) A young plant: (b) A senescent plant:

Transport and Effects of Auxins

Auxins are phytohormones (plant growth substances) that have a central role in a wide range of growth and developmental responses in vascular plants. **Indole-3-acetic acid** (IAA) is the most potent native auxin in intact plants. It was the first discovered and is the most studied. Although its actions on various aspects of plant growth are well known, it most commonly acts in concert with (or in opposition to) other phytohormones, especially cytokinins and gibberellins. The response of any particular plant tissue to IAA depends on the tissue itself, the concentration of the hormone, the timing of its release, and the presence of other phytohormones. For example, in undifferentiated tissue, the application of IAA and cytokinin in equal concentrations promotes xylem development, but a relatively higher concentration of auxin promotes rooting. Gradients in auxin concentration during growth prompt differential responses in specific tissues and contribute to the plant's organ development and directional growth.

AUXINS IN PLANTS:

The most important auxin produced by plants is **indole-3-acetic acid** (IAA). It plays important roles in a number of plant activities, although its action is often influenced by the presence of other plant growth factors. Auxin is important in:

- apical dominance
- positive phototropic response in stems
- positive gravitropic response in roots
- development of the embryo
- promoting cell elongation and growth in stem length
- promoting cell enlargement and differentiation in cambium (growth of secondary vascular tissues)
- leaf formation and fruit development
- root initiation and development
- delaying the onset of senescence. Young leaves and fruit produce auxins and while they do so, they remain attached to the stem and abscission is inhibited.

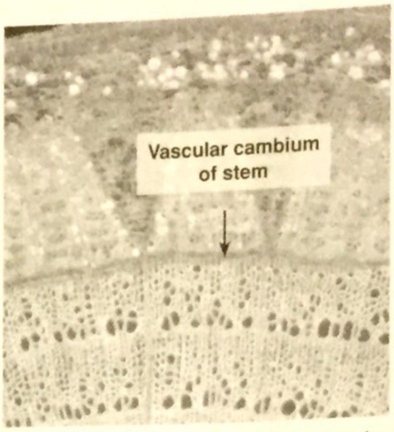
PRODUCTION OF AUXIN:

Auxin is synthesised in the meristematic tissues, mainly the root tips and shoot tips, but also in young leaves and flowers.

HOW AUXIN MOVES IN PLANTS:

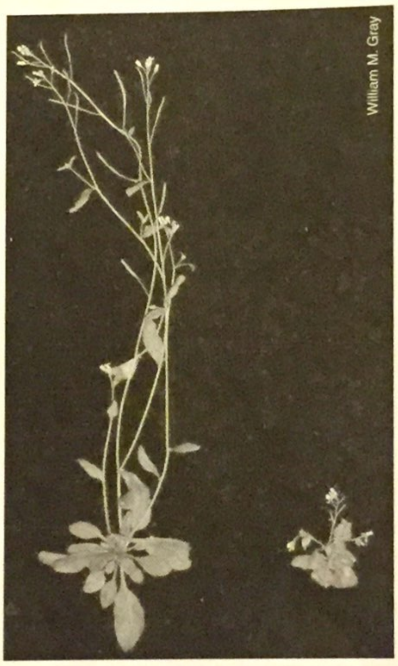
Synthesis of auxin is not always the site of action so it must be moved to other locations. Auxin moves through the plant by two mechanisms:

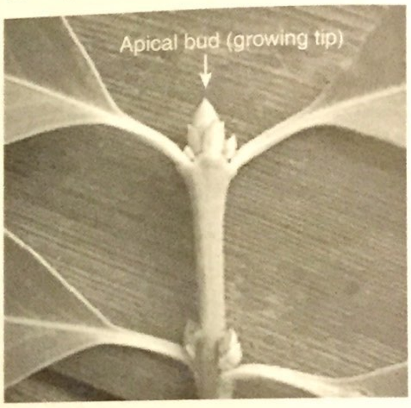
- through the phloem (in the sap) and the xylem (in the transpiration stream)
- from cell to cell by diffusion but also via membrane transporters



Auxin promotes the activity of the vascular cambium (above) and the differentiation of xylem and phloem. Other growth regulators (e.g. cytokinins) influence this by increasing the sensitivity of the tissues to IAA.

Auxin delays fruit senescence and is required for fruit growth. As the seeds mature, they release auxin, which diffuses to the surrounding flower parts, which develop into the fruit covering the seeds.





Auxins are responsible for apical dominance in shoots. Auxin is produced in the shoot tip and diffuses down to inhibit the development of the lateral buds.

Left: Auxin promotes growth in stem length. The effect is stronger if gibberellins are also present. This photograph shows a healthy *Arabidopsis* plant, next to a stunted auxin signal-transduction mutant.

1. Explain the role of IAA in the following plant growth processes:

   (a) Apical dominance: ____________________

   (b) Stem growth: ____________________

   (c) Secondary growth: ____________________

2. Explain why pruning (removing the central leader) induces bushy growth in plants: ____________________

   ____

   ____

3. Explain how IAA can bring about quite different responses in different plant tissues: ____________________

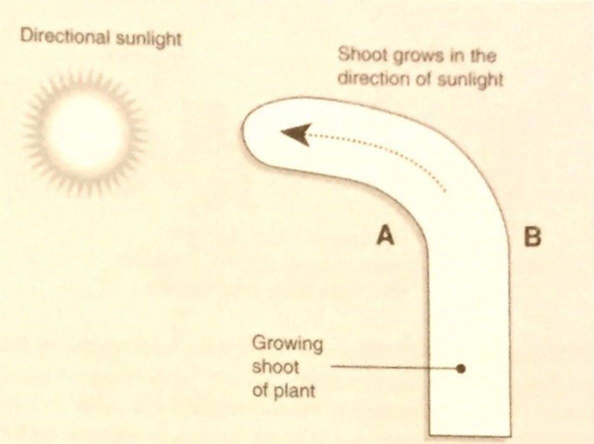
   ____

   ____

Investigating Phototropism

Phototropism in plants was linked to a growth promoting substance in the 1920s. A number of classic experiments, investigating phototropic responses in severed coleoptiles, gave evidence for the hypothesis that auxin was responsible for tropic responses in stems. Auxins promote cell elongation. Stem curvature in response to light can therefore result from the differential distribution of auxin either side of a stem. However, the mechanisms of hormone action in plants are still not well understood. Auxins increase cell elongation only over a certain concentration range. At certain levels, auxins stop inducing elongation and begin to inhibit it. There is *some* experimental evidence that contradicts the original auxin hypothesis and the early experiments have been criticised for oversimplifying the real situation. Outlined below are some experiments that investigate plant responses to light, and the role of hormone(s) in controlling these (also see following activities on phytohormones).

1. **Directional light:** A pot plant is exposed to direct sunlight near a window and as it grows, the shoot tip turns in the direction of the sun. If the plant was rotated, it adjusted by growing towards the sun in the new direction.



   (a) Name the hormone that regulates this growth response:

   ____

   (b) Give the full name of this growth response:

   ____

   (c) State how the cells behave to cause this change in shoot direction at:

   Point A: ______________________________

   Point B: ______________________________

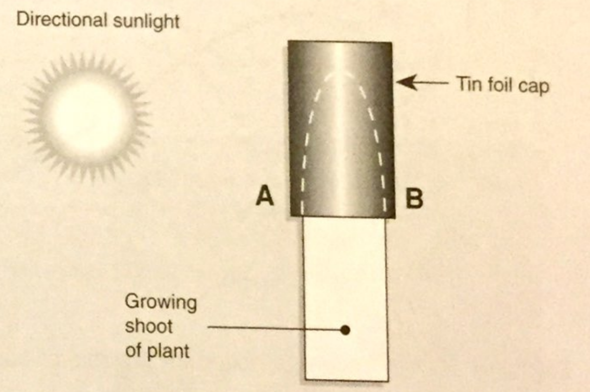
   (d) State which side (A or B) would have the highest concentration of hormone:

   ____

   (e) Draw a diagram of the cells as they appear across the stem from point A to B (in the rectangle on the right).

Draw your cells here:

2. **Light excluded from shoot tip:** With a tin foil cap placed over the top of the shoot tip, light is prevented from reaching it. When growing under these conditions, the direction of growth does not change towards the light source, but grows straight up. State what conclusion can you come to about the source and activity of the hormone that controls the growth response:



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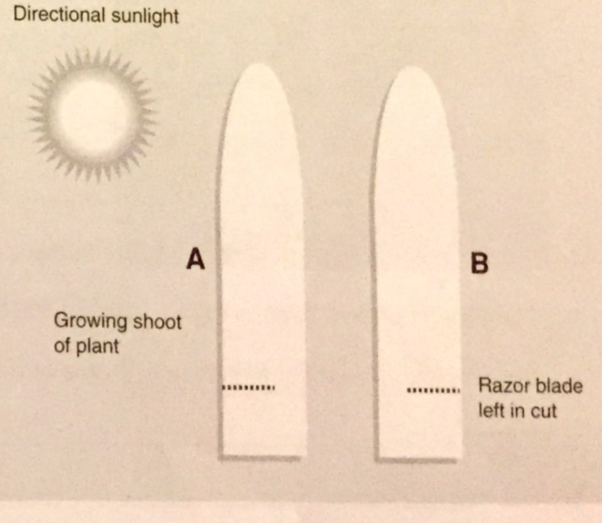
3. **Cutting into the transport system:** Two identical plants were placed side-by-side and subjected to the same directional light source. Razor blades were cut half-way into the stem, thereby interfering with the transport system of the stem. Plant A had the cut on the same side as the light source, while Plant B was cut on the shaded side. Predict the growth responses of:



   Plant A: ______________________________

   ____

   ____

   Plant B: ______________________________

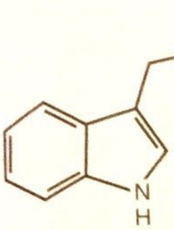
   ____

   ____

Apical Dominance, Bolting, and Leaf Loss

A wide variety of plant cells produce hormones to regulate growth and development. Identifying the hormones involved in specific plant processes and understanding their mechanism of action is not always straight forward because a combination of hormones and environmental factors often interact to produce a given response. Understanding these interactions has allowed humans to manipulate plant growth and development (e.g. stimulating growth, inducing fruit fall) to achieve a desired outcome.

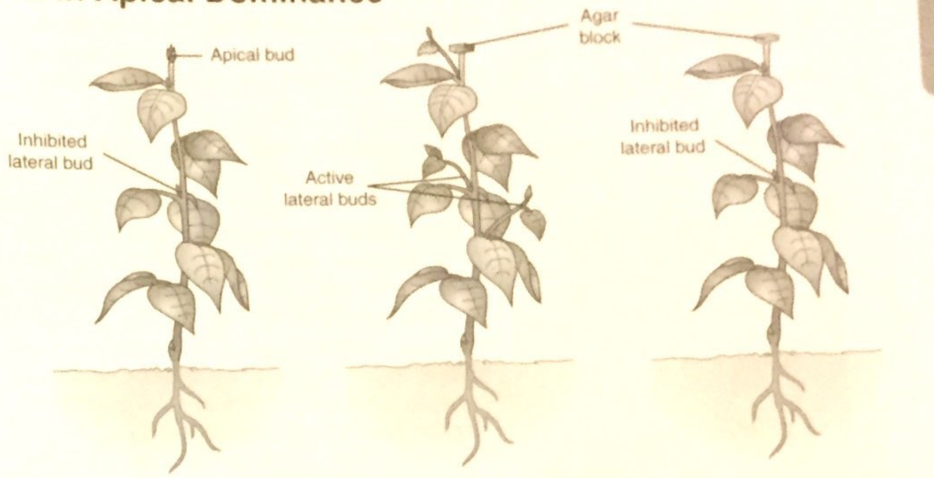
Experimental Evidence for the Role of Auxin in Apical Dominance



Indole-acetic acid (left) is the only known naturally occurring auxin. It is produced in the apical shoot and young leaves.

Auxin was the first substance to be identified as a plant hormone. Charles Darwin and his son Francis were first to recognise its role in stimulating cell elongation. Frits W. Went isolated this growth-regulating substance, which he called auxin, in 1926. Auxin promotes **apical dominance**, where the shoot tip or apical bud inhibits the formation of lateral (side) buds. As a result, plants tend to grow a single main stem upwards, which dominates over lateral branches.

The effect of auxin on preventing the development of lateral buds can be demonstrated experimentally (right).



No treatment
Apical bud is left intact.

Treatment one
Apical bud is removed; no auxin is applied.

Treatment two
Apical bud is removed; auxin is applied.

In an intact plant, the plant stem elongates and the lateral buds remain inactive. No side growth occurs.

The apical bud is removed and an agar block without auxin is placed on the cut surface. The seedling begins to develop lateral buds.

The apical bud is removed and an agar block containing auxin is placed on the cut surface. Lateral bud development is inhibited.

Two conclusions can be drawn from this experiment. (1) The apical bud contains a hormone that inhibits lateral growth because its removal promoted lateral growth. (2) The presence of auxin in the apical bud inhibits lateral growth because auxin applied to a cut stem tip could inhibit lateral growth and mimic the effect of an intact apical bud.

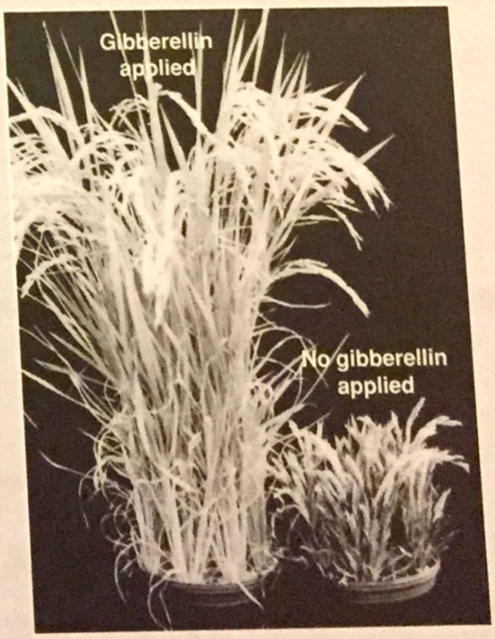
Gibberellins and Stem Elongation

Japanese rice farmers documented rapid stem elongation in the 1800s. This process, called **bolting**, resulted in tall, spindly rice plants that set no seed heads. In 1934, two Japanese scientists isolated the plant hormone responsible for the rapid growth. That hormone was **gibberellin**, and it acts by stimulating cell division and cell elongation. Although more than 78 gibberellins have since been identified, scientists believe that only gibberellin A controls stem elongation. The other gibberellins are believed to be intermediate forms of gibberellin A. Under natural conditions, production of gibberellin is triggered by environmental cues such as long days or a period of cold temperatures.

Evidence for Gibberellin's Role in Stem Elongation

Chemical analysis has revealed that bolting plants contain higher levels of gibberellin than non-bolting plants. Experimentally, the link between gibberellin and plant bolting can be tested quite simply by applying gibberellin to one group of plants, and not applying it to another group, which act as the control. Both groups are grown in the same conditions and the differences in stem elongation are measured at the end of set period. The plants treated with gibberellins have longer stems than the plants in the control group.

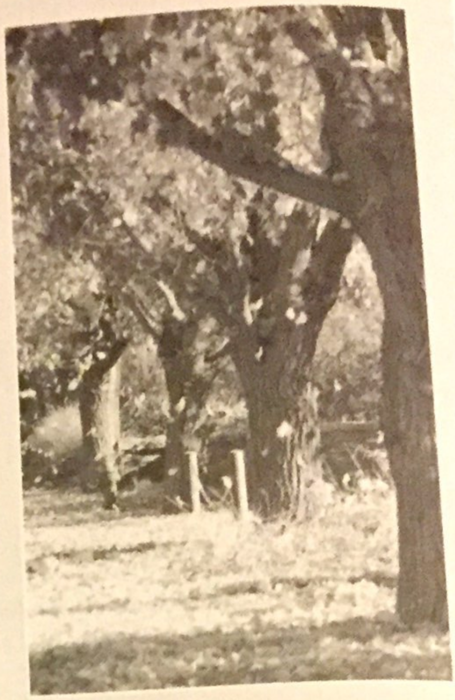
The use of gibberellin inhibitors have also been important in establishing the link between gibberellins and bolting. When gibberellin was applied to plants they bolted. However, plants in which gibberellin plus a gibberellin inhibitor was applied did not bolt. Because plants given the gibberellin inhibitor did not bolt, it can be assumed that gibberellin is the hormone responsible for this growth response.

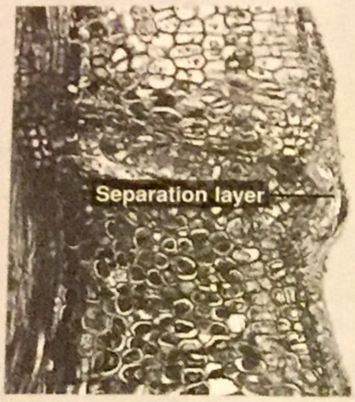


Photo, above: Plants treated with gibberellins have longer stems than the control group which had no gibberellins applied during the experimental period.

Leaf Loss in Deciduous Plants

Deciduous plants shed their leaves every year in a process called **abscission**. Leaf abscission usually occurs during the autumn (right), but some plants shed leaves in the presence of a large number of plant pests, such as aphids. During the 1960s, Frederick T. Addicott discovered a substance apparently capable of accelerating abscission in leaves and fruit (which he called abscisin), and which is now called **abscisic acid** (ABA). The hormonal regulation of leaf abscission is not yet fully understood, but scientists now believe that **auxin** (IAA) and **ethylene**, rather than ABA, are the primary hormones involved. Abscisic acid is believed to have a role in leaf ageing (senescence), a process that precedes abscission.





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The plant hormones **auxin** and **ethylene** work in synergy to cause leaves to fall. As the leaf ages, auxin levels within the leaf (and subsequently the abscission zone) drop. The plant becomes more sensitive to the effects of ethylene, and gene expression of enzymes involved in cell wall degradation (e.g. cellulase) increases. These enzymes begin to break down the cell wall in localised regions (the separation layer) at the base of the leaf stalk (petiole). As a result the leaf and its stalk fall away.

Photo left: Leaf abscission in an *Asclepia* leaf. Magnification x100.

1. Describe the role of **auxins** in apical dominance: __________

2. Describe the role of **gibberellins** in stem elongation: __________

3. Outline the experimental evidence supporting:

   (a) The role of **auxins** in apical dominance: __________

   (b) The role of **gibberellins** in stem elongation: __________

4. (a) Name the two hormones involved in leaf abscission: __________

   (b) Describe how these two hormones work synergistically together to cause leaf abscission: __________