AP* BIOLOGY

PLANTS: RESPONSES AND HORMONES

Teacher Packet

Plants: Responses and Hormones

Objective
To review the student on the concepts and processes necessary to successfully answer questions related to plant hormones and responses (tropisms).

Standards
Plant hormones and responses are addressed in the topic outline of the College Board AP Biology Course Description Guide as described below.

III. Organisms and Populations
- A. Diversity of Organisms
  - Evolutionary patterns
  - Survey of the diversity of life
  - Phylogenetic classification
  - Evolutionary relationships
- B. Structure and Function of Plants and Animals
  - Reproduction, growth, and development
  - **Structural, physiological and behavioral adaptations**
  - **Response to the environment**

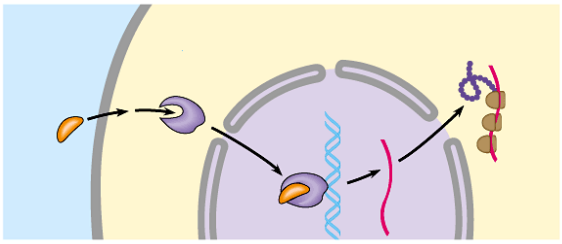
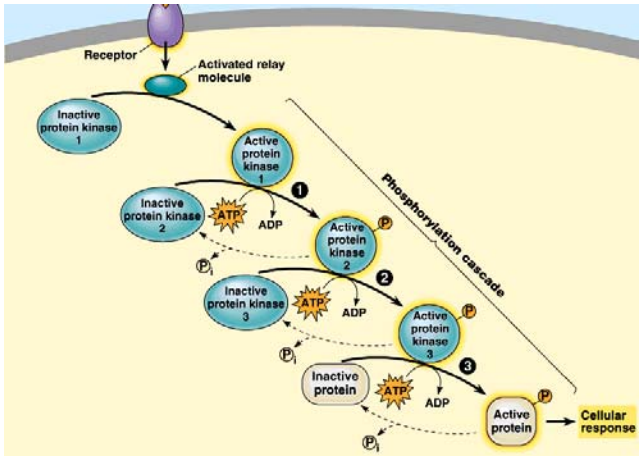
Questions on plant hormones and tropisms are common on the AP exam. As with many AP Biology free response questions, these topics are often intertwined with other topics. It is not uncommon to see a single question for example that links plant hormones with the human endocrine system. One could easily foresee a "cell communication" themed question for example that asks students to discuss hormones, neurotransmitters, etc. The list below identifies free response questions that have been previously asked over this topic. These questions are available from the College Board and can be downloaded free of charge from AP Central http://apcentral.collegeboard.com.

Free Response Questions	
2003 Question #2	2003 B Question #2
1999 Question #2	

Plants: Responses and Hormones

Plant Hormones

Plant Hormones: General Information
▪ Differentiation of plant tissue is governed by hormones. ▪ Most differentiation in plants is fully reversible. ▪ Remember: The hormone binds to a receptor, which initiates a biochemical cascade that will either cause manipulation of DNA to transcribe or cease transcribing OR the cascade will simply turn "on" or "off" a preexisting enzyme. ▪ Unlike the human endocrine system, plant hormones are not produced in specialized cells like glands.

Cell Signaling: How Hormones Work	
THREE STAGES OF A SIGNAL-TRANSDUCTION CASCADE 1. Reception- signal molecule (in this case a hormone) binding to receptor 2. Transduction- usually a change in shape, getting the signal into a form that can initiate a response 3. Response	
Receptor Types: Mechanisms of Cell Signaling	
Intracellular Receptors ▪ Location- The receptor is located inside the cell. ▪ Operating procedures- Nonpolar ligands (such as steroid based hormones) can diffuse through the lipid bilayer to reach the internal receptor. The activated receptor will eventually (directly or indirectly) effect transcription or translation.	
Cell Surface Receptors ▪ Location- The receptor is located on the cell surface. ▪ A signal transduction cascade ensues. Why a cascade? ▪ Each step of a signal transduction cascade may activate many proteins in the next step <u>amplifying</u> the signal. ▪ Each step is a "yes/no" point of control. →<u>Second messengers</u> may be used as well. These are soluble nonproteins (cAMP, Ca^{2+}). →<u>G linked proteins</u> are "diffusible signals in the cytoplasm"; however, they still stay near the cell surface and usually activate a cell surface enzyme. G linked proteins are activated by GTP, hence the name.	

Auxin: The Catch All Hormone

Stem Elongation
- Auxin is primarily responsible for stem elongation (roots & shoots) at apical meristems in plants.

Fruit Development
- Auxin is also essential in developing mature fruit. As seeds form, they release auxin resulting in the synthesis of the surrounding fruit.

Prevention of Abscission
- The presence of auxin prevents abscission (abscission- losing leaves, think "cutting" off the leaves). As auxin decreases, leaves drop.

Weed killer
- Certain types of synthetic auxin can be metabolized by monocots, but cannot be broken down by broadleaf weeds. One can fertilize a lawn with synthetic auxin in high doses which becomes toxic to the "weed"

Tropisms
- Auxin is responsible for phototropism and gravitropism described later.

Cytokinin: Promoting cytokinesis

- Cytokinin is produced in actively growing cells such as roots, embryos, and fruits.
- Auxin may help cells grow larger, but without cytokinins, cells don't actually divide.
- The presence of cytokinin slows aging and senescence in plants.
  -Florists can spray cytokinins on cut plants, so as to keep them fresh longer.

Gibberellins: Stem elongation

Stem Elongation
- Gibberellins are primarily responsible for stem elongation (think height) in plants but have little effect on root growth.
- Many hypothesize that auxin "acidifies" the cell wall to allow for expansion while gibberellins allow for expansin proteins to penetrate the cell wall causing expansion.
- Gibberellins are important for fruit development as the size of grapes for example increases greatly when treated with gibberellins.
- Add gibberellins to most dwarf plants and they will grow to regular size.
- Gibberellins are also responsible for breaking dormancy. The embryos of seeds contain high amounts of gibberellins and release the hormone upon intake of H_2O.

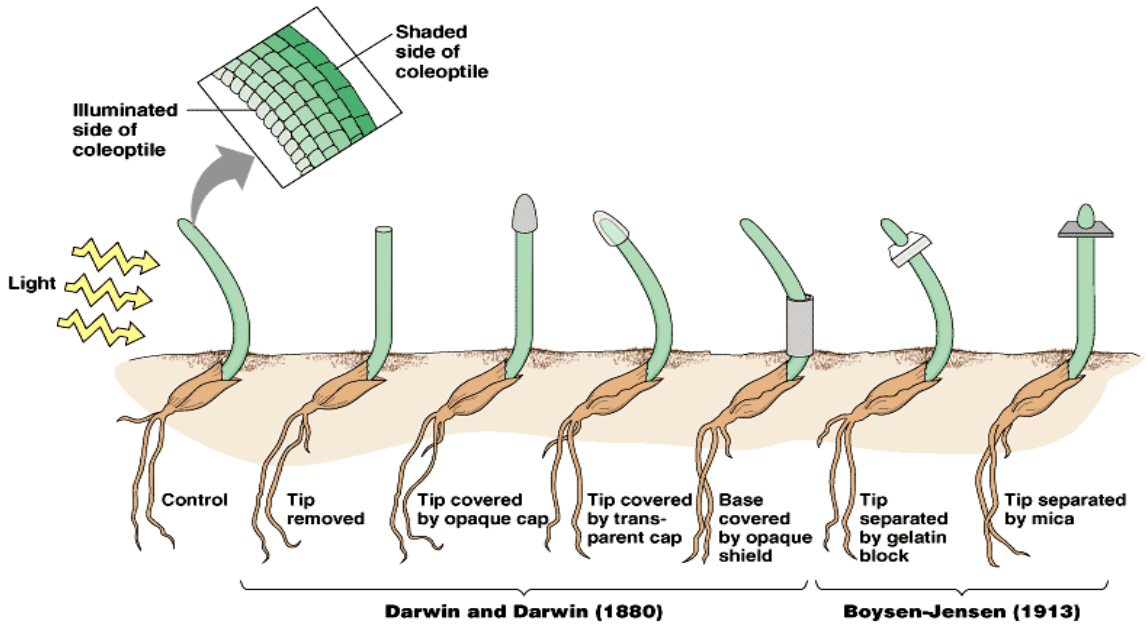
Abscisic Acid: "Cutting of leaves"- so they used to think

- Essentially the opposite of gibberellins and auxin as it inhibits growth. An increase in abscisic acid (ABA) results in preparation for dormancy such as winter.
- High levels of ABA results in seed creation.
- ABA is responsible for a certain level of drought resistance. When plants wilt, they produce ABA closing stomata and preventing water loss.
- When ABA is removed, dormancy is "lifted" and seeds begin growing. Levels of ABA may decrease for example when it finally rains in the desert

Ethylene: Fruit ripening
Triple Response ▪ Ethylene initiates the "triple response" which results in the "retreat, thickening, and curving" of a shoot as it grows. This is beneficial when growing up through the ground and encountering a large rock for example. Contact with the rock causes ethylene production which eventually results in growth around the obstacle. Apoptosis ▪ Apoptosis, programmed cell death, is often accompanied by an increase in ethylene. Leaf Abscission ▪ As auxin levels go down, the effects of ethylene become pronounced. Ethylene is responsible for the dropping of leaves. Leaves represent a large area across which water could be lost. This adaptation of "dropping leaves" helps to avoid desiccation in the winter. Fruit ripening ▪ Once seeds have matured, ethylene production increases causing a ripening and softening of fruit. Cell walls are broken down and sugars are synthesized. This process is an example of positive feedback: Ethylene initiates ripening and ripening increases synthesis of ethylene. Ethylene is a gas and therefore the effects of ethylene such as ripening can be enhanced by enclosing fruit in a bag. It should be noted that CO_2 has the opposite effect. CO_2 arrests fruit ripening.
Summary → Ethylene levels increase when plants are subjected to stress. It is as if the plant is shipping all resources to fruit production which will of course inadvertently increase the likelihood of passing on genes.

Tropisms: Responses to External Stimuli

Phototropism: Growing Toward the Light Source



The Phototropism experiments:

- Tip removal: Significant as this step shows that the tip (or something in the tip) is responsible for responding to the light
- Tip covered by opaque cap & tip covered by transparent cap: These steps are significant because they demonstrate that the tip must be present and must be exposed to light.
- Base covered by opaque shield: This step demonstrates that opaqueness itself is not responsible for interfering with phototropism.
- Gelatin block & mica separation: The gelatin block provides a permeable interface between the tip and the rest of the shoot. This is in contrast to the mica that does not allow for the diffusion of substances.

Conclusions→ A diffusible signal is transmitted along the length of the growing coleoptiles. The signal responds to light and promotes growth toward the light.

How does auxin work?

The most common hypothesis:

- Auxin migrates to the shady side of the shoot.
- As auxin migrates, it acidifies the cell wall.
- The drop in pH results in the activation of expansin proteins that interfere with hydrogen bonding between cellulose fibers.
- Ions are shuttled in and water follows resulting in expansion of the weakened cell walls.

Photoperiodism: Plants sensing a change in seasons

- A photoperiod represents the relative length of a day. Because the length of a day gradually changes throughout the year, plants can respond by flowering at the appropriate time.
- Photoperiodism was 1st discovered when a mutant tobacco plant flowered in winter instead of summer. After testing for several variables (moisture, temperature, etc.) it was determined that flowering occurred once "day length" (due to artificial light) of 14 hours or less resulted in flowering. This mutant plant was termed a "short day" plant.
- In later experiments, it was found that interrupting "day time" with brief periods of darkness resulted in no change in response. However, if darkness was interrupted by a brief period of light, plants failed to flower. This experiment showed that it was actually the amount of uninterrupted darkness that was critical for plant response. The melding of these two experiments, resulted in following terminology:
  -Short day plants: plants that require a minimum number of darkness hours in order to flower
  -Long day plants: plants that "set" a maximum number of darkness hours in order to flower
  -Day neutral plants: flower primarily due to maturity as opposed to day length

How does it work?

- A light receptor known as phytochrome is found in leaves and is responsible for responding to the length of darkness. Experiments show that removal of all but a single leaf will still result in a proper response.
- Plants are so sensitive to changes in the length of nighttime that some plants flower on the same day every year.
- Until recently, evidence for a flowering hormone had been overwhelming but isolation of the actual hormone responsible had remained elusive. Scientists named the hypothetical hormone florigen before its actual discovery. A group of Japanese scientists is now claiming to have found the actual florigen protein.

Gravitropism, Thigmotropism, and Turgor Movement

Gravitropism

- Auxin is primarily responsible for growth from a seedling. How is it that a seed planted in the ground out of the sunlight is able to consistently send roots down and shoots up during development?
- Statoliths found in the cells of root tips contain "loose" starch grains that respond to gravity. The starch grains will settle to the bottom denoting "up" and "down" for the purposes of development. This somewhat simplistic hypothesis has been scrutinized somewhat lately. It seems that cytoskeletal elements may also be heavily involved.

Thigmotropism

- Thigmotropism is directional growth in response to touch or mechanical stimuli.
- Thigmotropsim specifically results in a curling pattern of growth when mechanical stimuli are present. This allows vines to "grasp" onto the surrounding support structure.

Turgor Movement

- Turgor movement is different from thigmotropism in that is the immediate response to touch.
- K+ channels open and close in contractile parts of plants (similar to neuron/muscle interactions in animals) in reaction to a stimulus. As K^+ moves, water moves due to osmosis. When water moves, leaves change shape and "fold" inwardly.

Multiple Choice

Questions 1-4 refer to the following plant hormones

(A) Auxin
(B) Gibberellins
(C) Ethylene
(D) Cytokinin
(E) Abscisic acid

1. This hormone is responsible for cell division in plants.

D	Ctyokinin (think cytokinesis) is responsible for cell division in plants.

2. If a fruit were to fail to ripen, it would most likely be due to mutated receptors for this hormone.

C	Ethylene is primarily responsible for fruit ripening. A mutation in ethylene receptors would interfere with the proper ripening of fruit. This question is a bit tricky as auxin and gibberellins are involved in the production of fruit.

3. This hormone is responsible for phototropism and apical dominance.

A	Auxin is responsible for phototropism and apical dominance among other things.

4. An increase in this hormone will result in decreased water loss.

E	Abscisic acid production in wilting plants results in the closing of stomata.

5. While conducting experiments, a scientist notices that a particular plant behaves in a peculiar way. Through further study, she concludes that statoliths are not produced in this plant. Which of the following best describes events that she saw during her experiments?

(A) The plant was unable to send shoots upward and roots downward in a manner consistent with the control group.
(B) Stomata remained closed for extended periods of time when compared to the control group.
(C) The plant did not grow toward a light source when placed in the dark.
(D) The plant was unable to produce fruit.
(E) The plant dropped its leaves.

A	Statoliths are involved in gravitropism. The lack of statoliths will result in slower or possibly abnormal growth of shoots and roots. The closing of stomata as it relates to hormones is due to abscisic acid. Answer choice "C" is describing phototropism which is controlled primarily by auxin. Fruit production is related to auxin and gibberellins while the ripening of fruit is due to ethylene. The dropping of leaves is in response to ethylene.

6. Chrysanthemums typically bloom in the fall. A local florist, however, wants to hinder the blooming of the Chrysanthemums until May for Mother's Day. Which of the following will be his best strategy for stalling the flowering process until May?

   (A) Store the plants indoors next to a window without shades.
   (B) Place lights on timers so that the plants are exposed to short periods of light in the middle of the night.
   (C) Place the plants into a dark room before sunset where they will receive no light until after sunrise.
   (D) Place the plants next to a window in an airtight bins flushed with ethylene.
   (E) Place the plants next to a window in an airtight bins flushed with CO_2.

B	If a plant typically blooms in the fall it a short day plant. It therefore requires long periods of darkness in order to bloom. Short periods of light exposure will essentially "break up" the long night and the plant will fail to bloom. If one were to store the plants near a window, this would be no different from storing the plant outside; the plant would bloom in the fall.

7. Each of the following is involved in response to stress EXCEPT:

   (A) Ethylene
   (B) Abscisic acid
   (C) Closing of stomata
   (D) Turgor movement
   (E) Photoperiodism

E	Photoperiodism is not a stress related response.

8. If phytochrome molecules were completely removed from plants, which of the following would be the most greatly affected?

   (A) Thigmotropism
   (B) Turgor movement
   (C) Photoperiodism
   (D) Gravitropism
   (E) Ethylene production

C	Phytochrome molecules are the light sensitive molecules used in photoperiodism.

9. The function of a signal transduction cascade is

I. synthesis of receptors
II. amplification of the signal
III. increased control of cellular processes

(A) I only
(B) II only
(C) III only
(D) I and II only
(E) II and III only

E	Signal transduction cascades are valuable as a means of signal amplification and as individual points of control during cellular processes.

10. Which of the following hormones would most likely be able to penetrate the cell membrane?

(A) Polar hormones
(B) Lipid soluble hormones
(C) Amino acid based hormones
(D) Those that utilize a G-protein pathway
(E) Hormones containing many hydrogen bonding sites

B	Lipid soluble substances are able to most easily traverse the phospholipid bilayer of the cell membrane. Amino acid based hormones and hormones with may hydrogen bonding sites represent polar molecules. Polar substances do not easily penetrate the cell membrane. The G-protein pathway is specific to membrane bound receptors.

Free Response

1. Hormones are able to initiate cellular responses in plants by binding to intracellular receptors or membrane bound receptors.

   A. Describe how each of these two mechanisms works to illicit a response.

1 point for each of the following (6 point max)
_Hormones act on target cells only. Target cells are those with receptors for that particular hormone.
_Lipid soluble or nonpolar hormones will bind with intracellular receptors.
_Intracellular receptors typically effect transcription.
_Lipid insoluble or polar hormones will bind to membrane bound receptors.
_Lipid insoluble hormones typically initiate biochemical or transduction cascades.
_Biochemical cascades are significant because each step in the process represents a point of control.
_Biochemical cascades are significant because each protein may activate several proteins thereby amplifying the signal.
_Elaboration point: contextually correct description of G proteins, 2nd messengers, or other related detail

   B. Describe hormonal, anatomical, and metabolic adaptations of plants that allow them to live in an arid environment.

1 point for each of the following (6 point max)
Hormones
Ethylene
_Dropping of leaves in winter to avoid desiccation.
Gibberellins
_When introduced to water, embryos within dormant seeds release gibberellic acid and break dormancy.
Abscisic acid
_Increased ABA results in closing of stomata.
_When introduced to water, dormant seeds begin to germinate as ABA levels decrease
Additional
_Cuticle or cutin protein is an airtight, water tight covering found on leaves to avoid desiccation
_Stomata located on the underside of leaves result in less water loss.
_The CAM pathway of photosynthesis allows for gas exchange through stomata at night.
_Root growth (depth, etc.) may adjust due to water availability (deeper roots to access water).
_Smaller or “less broad” leaves or needle-like leaves result in decreased surface area for water loss.
_Elaboration point: leaf angle toward the sun changes to decrease exposed area, etc.

Free Response

2. Plants are responsive to light.

A. Describe the mechanism by which phototropism takes place.

1 point for each of the following (4 point max)
_Auxin migrates to the shady side of the shoot when exposed to light. _As auxin migrates, it acidifies the cell wall. _The drop in pH results in the activation of expansin proteins _Expansin proteins interfere with hydrogen bonding between cellulose fibers OR "breakdown" cellulose. _Ions are shuttled in and water follows resulting in expansion of the weakened cell walls. _When the "shady side" cells expand greatly and the "sunny side" cells do not, the plant grows toward the light.

B. Describe the regulation of the flowering process of a plant and explain the evolutionary significance of this type of regulation.

1 point for each of the following (5 point max)
_Length of uninterrupted darkness determines the time of year at which a plant will flower. _Naturally this phenomenon allows for plants to flower during the proper season _Flowering during the proper season increases the likelihood that pollinators, etc. will be active. _Phytochrome is light receptor responsible for "sensing" light. _Phytochrome is thought to stimulate florigen protein which initiates flowering. **2 pt max for the following:** _Short day plants: require a minimum number of darkness hours in order to flower OR flower during long nights _Long day plants: plants that "set" a maximum number of darkness hours in order to flower OR flower during short nights _Day neutral plants flower primarily due to maturity as opposed to day length

C. Seeds sprout and send shoots upward and roots downward even though they may be underground and unexposed to light. Explain how this is possible.

1 point for each of the following (3 point max)
_ Statoliths are involved in "sensing" gravity. _ Statoliths contain "loose" starch grains that respond to gravity. _Starch grains will settle to the bottom denoting "up" and "down" for the purposes of development _Auxin concentrations are adjusted based on this gradation resulting in properly oriented roots and shoots.