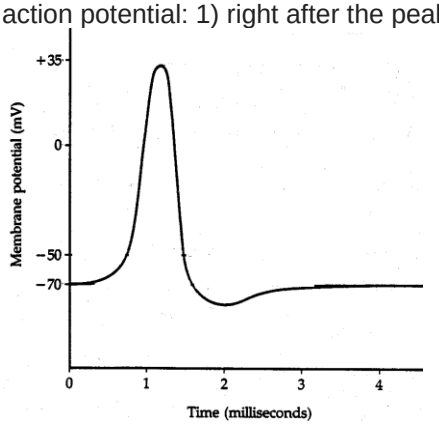
Supplemental Material

CBE—Life Sciences Education

Jackson *et al.*

Week 2:
Question 1:
(16 points) A. Make a Flux/Flow thought organizer for the movement of K+ at two points in a mammalian action potential: 1) right after the peak, 2) 2/3 of the way through the repolarization phase.



Instead of uploading your drawings, provide the following for each thought organizer.
Concentration of K+ inside:
Concentration of K+ outside:
Membrane potential:
Driving force 1:
Direction of driving force 1 (into or out of cell):
Driving force 2:
Direction of driving force 2 (into or out of cell):
Source(s) of resistance:

(14 points) B. Compare the rate of K+ movement between the two times. Defend your answer.

Key 1: (30 points)
A. (16 points, 1 point for each line; it doesn't matter which force is 1 and 2)
1) right after the peak of an Action Potential
Concentration of K+ inside: 150 mM
Concentration of K+ outside: 5 mM
Membrane potential: around +35 mV (do not need exact number)
Driving force 1: Chemical (or Concentration or Diffusion)
Direction of driving force 1 (into or out of cell): out of the cell
Driving force 2: Electrical
Direction of driving force 2 (into or out of cell): out of the cell
Source(s) of resistance: membrane, not channels (they're open)

2) 2/3 of the way through the repolarization phase
Concentration of K+ inside: 150 mM
Concentration of K+ outside: 5 mM
Membrane potential: around -70 mV (do not need exact number)
Driving force 1: Chemical (or Concentration or Diffusion)
Direction of driving force 1 (into or out of cell): out of the cell
Driving force 2: Electrical
Direction of driving force 2 (into or out of cell): into cell
Source(s) of resistance: membrane, not channels (they're open)

B. (14 points; order of explanation and exact phrasing are not important)
- The rate of K+ movement at the peak is greater than at 2/3 of the way though the repolarization phase. (2 points)

- The rate of movement of K+ is proportional to the sum of the driving forces acting on K+ over the resistance to movement of K+. (2 points)
- The resistance (or conductance) to K+ movement is very similar at both time points. (2 points)
- The concentration of K+ inside and outside the cell is basically the same over the entire action potential, so the large outward driving force due to the K+ concentration gradient is always the same. (2 points)
- The electrical driving force on K+ at the peak is also outward, as the positive charge inside the cell repels the positive K+ ion. (2 points)
- The electrical diving force on K+ halfway through the repolarization phase is inward, as the negative charge inside the cell attracts the positive K+ ion. (2 points)
- Since the outward driving force leading to movement of K+ at the peak (chemical+electrical) is greater than the outward driving force halfway through the repolarization phase (concentration-electrical), K+ flux is greater at the peak. (2 points)

Question 2:
(10 points) If the inactivation gate of the V-Na channel was removed, I predict the action potential would have a greater amplitude (peak at a more positive number), probably reaching ENa but going no further.
A. Do you agree with my prediction? Defend your answer using electrophysiology.
B. Predict two other things that would happen if the inactivation gate of the V-Na channel was removed.

Key 2 (10 points)
A. (6 points) If the V-Na's stay open, the resistance to Na movement will stay low allowing Na to continue moving (2 points) until the two forces acting on it, the diffusion and electrical forces (2 points), are equal and opposite, which is ENa (2 points). (Since there will be some K+ conductance, allowing K+ out, the peak may not completely reach ENa.)

B: (4 points; 2 points per predication)
1) The repolarization phase would take much longer (less steep slope) because Na+ would continue to enter the cell while K+ is leaving.
2) The absolute refractory period would be lost.
3) Other reasonable answers.

Question 3:
(18 points) Create a flow diagram to explain how the electric signal from a neuron is transmitted to another neuron or muscle cell at a synapse.

Key 3: (18 points; 2 points per line; students can combine lines and receive full credit)
Depolarization message on pre-synaptic neuron reaches axon terminal
--causes--> V-Ca++ channels open
--causes--> (decreased resistance to Ca++ movement thereby allowing) Ca++ diffusion into the axon terminal
--causes--> Ca++ stimulates neurotransmitter vesicles to bind to pre-synaptic membrane
--causes--> release of neurotransmitter into synaptic cleft
--causes--> neurotransmitter to bind to neurotransmitter receptors on post-synaptic membrane
--causes--> neurotransmitter receptors open
--causes--> (decreased resistance to K+ and Na++ movement thereby allowing) Na+ diffusion into the post-synaptic terminal
--causes--> depolarization of the post-synaptic membrane

Week 3:
Question 1:
(10 points) Predict what would happen to the force of muscle contraction if in troponin had a lower affinity to Ca++. Use a flow diagram to defend your answer.

Key 1: (10 points; 2 points per line; students can combine lines and receive full credit)
--causes--> less TN+Ca++ binding

--causes--> fewer TM moving off myosin-binding sites on actin
--causes--> decreased cross bridge cycling
--causes--> decreased sarcomere contraction
--causes--> decreased force of muscle contraction

Question 2:
(8 points) Predict what would happen to skeletal muscle contraction if there are twice as many Ca++ pumps on the SR. Defend your answer using Mass Balance reasoning.

Key 2: (8 points total)
Twice as many Ca++ pumps on the SR will double the rate at which Ca++ leaves the cytoplasm (2 points). If the rate out of the cytoplasm increases and the rate into the cytoplasm remains the same (2 points), the amount of Ca++ in the cytoplasm will not peak as high and will decrease faster (2 points). Therefore the strength and length (duration) of muscle contraction will decrease (2 points).

Question 3:
(10 points) When you begin to run your Tidal Volume increases. Explain how this works using the mechanics of ventilation (inhalation and exhalation). Do not include neurons in your answer.

Key 3: (10 points total)
When I start running, I contract my diaphragm (and intercostals) harder (2 points)
and increase the size of my thoracic cavity during inhalation (2 points).
This will decrease the atmospheric pressure in my lungs more than I was resting (2 points).
This will increase the atmospheric pressure gradient (2 points),
thus increasing the volume of air that enters (and hence leaves) my lungs (2 points).

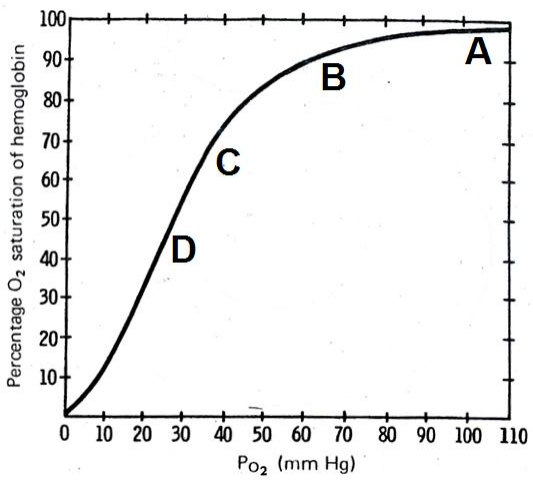
Week 4:
Question 1:
Use a flow diagram to explain how the PCO_2 of your blood impacts the pH of your cerebral spinal fluid. For arrows use –cause-->

Key 1: (14 points total; 2 points per line)
Increase in PCO2 of blood
--causes--> decrease in PCO2 gradient between blood and CSF
--causes--> decrease in CO2 diffusion out of CSF (or, if gradient reverses, CO2 diffusion into CSF)
--causes--> increase in PCO2 of CSF
--causes--> increase in CO2 + H2O to HCO3 reaction due to Le Châtelier's Principle (Law of Mass Action)
--causes--> increase in HCO3 to HCO2- + H+ reaction due to Le Châtelier's Principle (Law of Mass Action)
--causes--> lower pH of CSF due to the change in the number of H+

Student could discuss the reverse (e.g., decrease instead of increase).

Question 2:
Match each point on the oxyhemoglobin dissociation curve with the red blood cell in the appropriate conditions.
RBC in Aorta
RBC half way through the capillary found in your brain
RBC in Vena Cava
RBC in Vena Cava of a person running a marathon--who is at mile 18

Defend your predictions.



Key 2:
(12 points total; 1 point for each correct match; 2 points for each explanation—other reasonable explanations might be possible, use your best judgement)
A RBC in Aorta—RBC in the Aorta has not gone through a capillary bed since picking up oxygen in the lung.
B RBC half way through the capillary found in your brain—RBC halfway through a capillary bed has delivered a small amount of its oxygen to working tissue.
C RBC in Vena Cava—RBC in Vena Cava has completed passage through a capillary bed where it delivered about 30% of its oxygen to working tissue.
D RBC in Vena Cava of a person running a marathon--who is at mile 18—The working tissue in a marathon runner is using more oxygen, increasing the gradient so that the RBC delivers more of its oxygen.

Question 3:
(18 points) Explain how an action potential on a cardiac muscle cell membrane is generated. You may want to make a labeled AP diagram (that you won't upload) to help you.

Key 3: (18 points total; words in parenthesis not required)

If the student answered based on the Khan Academy video:
Depolarization message enters cell via gap junction (2 points)
signaling V-Na+ channels to open quickly. (2 points)
Na+ ions enter cell down electrochemical gradient, depolarizing cell. (2 points)
V-Na+ channels then close via inactivation gate. (2 points)
V-K+ channels open in response to the initial depolarization. (2 points)
K+ ions leave cell down electrochemical gradient, slightly repolarizing cell. (2 points)
V-Ca++ channels slowly open in response to the initial depolarization. (2 points)
K+ ions leave and Ca++ ions enter cell down electrochemical gradient, keeping the cell depolarized/at plateau. (2 points)
V-Ca++ close and V-K+ stay open, allowing K+ ions exit cell down electrochemical gradient, repolarizing cell. (2 points)

If the student answered based on my comments on Piazza:
Depolarization message enters cell via gap junction (2 points)
signaling V-Na+ channels to open quickly. (2 points)
Na+ ions enter cell down electrochemical gradient, depolarizing cell. (2 points)
V-Na+ channels then close via inactivation gate. (2 points)
"Faster" V-K+ channels open in response to the initial depolarization and K+ ions leave cell down electrochemical gradient, slightly repolarizing cell. (2 points)

V-Ca+ open slowly in response to the initial depolarization. (2 points)
K+ ions leave and Ca++ ions enter cell down electrochemical gradient, keeping the cell depolarized/at plateau. (2 points)
"Slower" V-K+ open very slowly in response to the initial depolarization and V-Ca++ close. (2 points)
K+ ions exit cell down electrochemical gradient, repolarizing cell. (2 points)

Week 5:

Question 1:

(21 points) Blood pressure drops in the carotid artery.
A. Give a brief physiological explanation of what happens in each set of cells as a result.
1) Trigger zone of the baroreceptor (the sensory neuron)
2) cell body and axons of motor neurons of the sympathetic system
3) ventricular muscle cells
4) SA node cell
5) smooth muscle cells responsible for vasodilation/vasoconstriction
B. Use mass balance reasoning to explain the change in arterial blood pressure resulting from the actions in part A.

Key 1: (21 points total)
A. (15 points; 3 points per line)
1) Graded potential (receptor potential) decreases leading to fewer action potentials being generated at the trigger zone (because threshold is not reached).
2) More EPSPs are being generated on the cell body which increases action potential frequency on motor neuron.
3) Sympathetic motor neurons firing leads to an increase Ca++ levels in cardiac muscle cells, increasing the force of contraction.
4) Sympathetic motor neurons firing leads to an increase in the slope of the pacemaker potential, increase the heart rate.
5) Sympathetic motor neurons firing leads to an increase in contraction of the smooth muscle cells (FYI this is also due to an increase in Ca++ levels), leading to vasoconstriction.
B. (6 points)
After the events in part A, increased HR and SV will lead to increased CO which increases the rate in of blood into the arteries (2 points). Arterioles vasoconstriction increases resistance to blood movement out of the arteries which decreases the rate out of blood out of the arteries (2 points). An increase in rate in and decrease in rate out, increases the volume of blood in the arteries, which hence increases blood pressure (2 points).

Question 2:

(10 points) If I give a drug to a patient that causes the Na+/K+ pumps in their cardiac muscle cells to decrease activity, what should happen to the rate of relaxation between heart beats (contractions)? Explain your reasoning using a flow diagram. For arrows use –cause-->

Key 2: (10 points total; 2 points per line, can combine lines and get full credit)
--causes--> reducing the [Na+] gradient OR extracellular [Na+] will decrease and increase intracellular [Na+]
--causes--> decrease Na+ diffusion into cell via NCX exchanger
--causes--> decrease Ca++ diffusion out of the cell
--causes--> slower decrease in cytoplasm [Ca++]
--causes--> increase in [Ca++] during relaxation
--causes--> decrease in rate of relaxation (not required to include)

Question 3:

(6 points) A mouse with a mutation in the *per gene* always has very high levels of PER protein. Propose a function of the mutation and defend your answer. Predict the sleeping behavior of the mouse.

Key 3: (6 points total)

The negative feedback on *per* expression is broken (2 points). The mutation likely impacts the PER ability to either form a dimer with CRY or bind to CLK/BMAL1 (2 points for one of these answers). This mouse will be arrhythmic (2 points).

Week 6:

Question 1:
(8 points) When a tree is alive it has energy stored in its living parts (e.g., roots, trunk, branches and green leaves). When the tree dies all the parts are still there (including fallen brown leaves) before decomposition begins.

Part A) How much of the energy stored in the living tree is still there in the dead tree before decomposition begins?

a) ALL of the energy
b) MOST of the energy
c) SOME of the energy
d) A LITTLE of the energy
e) NONE of the energy

Part B) Explain your reasoning.

Key 1: (8 points total)
Part A) 2 points for choosing a or b (ALL or MOST). 0 point for choosing c, d or e.

Part B) Most or all of the energy is still there because the energy stored in the tree is stored in the chemical OR C-C/C-H bonds (2 points) of organic molecules OR carbs, fats, proteins (2 points) and the organic molecules OR carbs, fats, proteins are still there after the tree dies (2 points).

Question 2:
(10 points) Consider the mass of a growing rose bush in Seattle. Many atoms contribute to the plants total mass. For the following question, we'll just consider the mass of carbon atoms.

A) State which biological process(es) (i.e., Photosynthesis and/or Cellular Respiration) contribute to the mass of carbon changes in the bush in the following 5 times of the year.
1. Autumn after leaves fall off
2. Winter
3. Spring before new leaves grow
4. Spring after new leaves grow
5. Summer

B) Indicate if the mass of carbon increases, decreases or stays the same in the bush in the following 5 times of the year.
1. Autumn after leaves fall off
2. Winter
3. Spring before new leaves grow
4. Spring after new leaves grow
5. Summer

Key 2: (10 points; 1 points per line)
A)
1. Cellular Respiration
2. Cellular Respiration
3. Cellular Respiration
4. Cellular Respiration and Photosynthesis
5. Cellular Respiration and Photosynthesis
B)

1. Decreases
2. Decreases
3. Decreases
4. Increases
5. Increases

Question 3:
(16 points)
Part A) Fill in the paragraph below to trace the energy of a blue photon in a wavelength that chlorophyll a does not absorb to pheophytin and describe how the energy is transferred from one place to another. Explain

Energy in blue photon absorbed by _____. Energy is now in an _____. That energy is transferred via _____ to _____ and is now in an _____. That energy is transferred via _____ to reaction center chl a and is now in an _____. That energy is then transferred to pheophytin via _____.

Part B) Assume an antenna complexes can transfer energy from 10 photons per second to pheophytin and that there are 400 reaction center chl a's per μm^2 of leaf area. Under which light intensity would leaves heat up more: 4000 photons per μm^2 per second or 6000 photons per μm^2 per second. Defend your answer using your knowledge of photons and pigments.

Key 3: (16 points total)
Part A) (8 points; 1 point per blank)
Energy in blue photon absorbed by __*chl b OR carotenoid*__. Energy is now in __*excited electron*__. That energy is transferred via __*resonance transfer*__ to __*any other antennae pigment*__ and is now in an __*excited electron*__. That energy is transferred via __*resonance transfer*__ to reaction center chl a and is now in __*excited electron*__. That energy is then transferred to pheophytin via __*electron transfer*__.

Part B) (8 point, information in parentheses not required)
The leaf would heat up more under the 6000 photons per μm^2 per second light intensity (2 points). The plant can use 4000 (10*400) photons per μm^2 per second for photosynthesis (2 points). The energy from the extra 2000 photons per μm^2 per second will be absorbed by antenna pigments and excite their electrons (2 points). Since the energy cannot be transferred to the reaction center it will be released as heat or fluorescence (when the electrons return to a low energy state) (2 points). Students might also talk about absorption and reradiation of energy by nonpigment plant molecules.

Week 7
Question 1:
(8 points) Blue and red photons hit a chloroplast, but no NADP+ is available. Would appreciable amounts of O_2 be formed? Explain your reasoning.

Key 1: (8 points total)
Without NADP+, there is no final electron acceptor for the electron from the reaction center chlorophyll in PSI to go to (2 points).
Therefore there is no electron flow from PSII to PSI (2 points). (another way to say this is: Now there is no "hole" in the reaction center chlorophyll in PSI for the electron from PSII to go to.)
Therefore there is no electron missing from the reaction center chlorophyll in PSII (2 points). (another way to say it is: Therefore, there is no "hole" in PSII for the electron from H_2O to go to.)
Therefore, H_2O is not split to produce electrons, protons, and O_2 (2 points).

Question 2:
(10 points) An investigator is trying to determine the mode of action of an herbicide. They expose isolated chloroplasts to the herbicide and then red light. They observe a build-up of ATP and NADPH in

the chloroplasts but no reduction in CO2 levels in the growth medium. How can this observation be explained?
a) Propose a mechanism for the herbicide
b) Defend your answer
c) Will ATP and NADPH continue to be made hours after these observation if light is kept available? Defend your answer.

Key 2: (10 points total)
a) The student must propose a mechanism that has something to do with stopping the Calvin cycle. They can just say, stops the Calvin cycle, they can talk about inhibiting Calvin cycle enzymes etc. (2 points).
b) There should be two ideas included in the defense. 1) Since ATP and NADPH are still being produced the light reactions are still working (2 points). 2) Since there is no reduction in CO2 levels the Calvin cycle must not be fixing it (2 points).
c) No, the light reaction depend on the availability of NADP+ (2 points). If NADPH is not used in the Calvin cycle and recycled to NADP+ (2 points), then the light reactions will stop (as described in Key 1).

Question 3:
(10 points) You determine the water potential (ψ_W) of tissue in a potato to be -0.9 MPa.
A) When you drop this piece of potato into a beaker of distilled water, what will happen? Explain your reasoning.
B) What could you do to the system in the lab to prevent this from happening?

Key 3: (10 points total)
A) The water potential of pure/distilled water is 0 MPa or very close to 0 MPa (2 points). Water moves from higher to lower water potential (2 points). Therefore, water will move into the potato (2 points).
B) You could add enough solute to the water to decrease the water potential of the solution (2 points) to less than -0.9 MPa (2 points).
OR
You could somehow exert pressure on the cell to increase the water potential of the cell (2 points) to greater than 0 MPa (2 points).

Week 8:
Question 1:
(14 points) Explain how water moves from a xylem vessel in the roots of a plant into the atmosphere outside one of the plant's leaves. Use a flow diagram. Start with atmosphere.

Key 1: (14 points; 2 points per line; students can combine lines and receive full credit)
Water potential gradient between atmosphere and leaf air space
--causes-->water vapor flux (or movement or diffusion) from leaf air space to air (through stomatal pore)
--causes-->(relative) humidity OR water potential in leaf air space to decrease
--causes-->water potential gradient between leaf air space and liquid water (at menisci))
--causes-->evaporation of water from menisci
--causes-->surface tension to be created at menisci (can also say negative pressure or negative pressure potential is created)
--causes-->water to be pulled from apoplast of surrounding cells and xylem

Question 2:
(6 points) The leaf epidermal cells of a plant at mid-day have a water potential (Ψ_W) of –1.5 MPa, and the stomates are fully open. What is the water potential (Ψ_W) of the guard cells? Defend your answer.

Key 2: (6 points total)
Water potential of the guard cells will be -1.5 MPa (2 points).
If stoma are fully open, then guard cell volume isn't changing (that is, water is not entering or leaving the cell guard cells) (2 points).
The guard cells and the leaf epidermal cells must be at equilibrium (2 points).

Question 3:
(14 points) The fungus *Helminthosporium maydis* was the cause of the corn blight which destroyed most of the corn crop in the US in 1970. The fungus 'starved' the host plants by severely restricting their CO_2 intake.
A) How does infection by the fungus inhibit a plant's CO_2 intake, when its primary action was to prevent potassium uptake by plant cells? Use a flow diagram ending with "reduced CO_2 uptake"
B) Propose a mechanism for how *Helminthosporium maydis* can limit potassium uptake by plant cells.

Key 3: (14 points total)
A) (8 points)
Guard cells cannot take up K+ (2 points)
-->Water potential of guard cells cannot decrease as much or as early in the day (Student make also talk about solute potential not decreasing or osmolarity not increasing. All three are accepted. 2 points)
-->Water does not enter guard cells as much or as early in the day (2 points)
-->Stomates are less open OR stomate aperture is smaller OR stomates are less open throughout the day etc. (2 points)
-->Reduced CO_2 uptake (not required)

Students might or might not talk about how increasing sucrose over the day will cause the stomates to open later in the day. What is important here is understanding the if guard cells cannot take up K+ then there will be higher resistance to CO_2 uptake because of the stomates being more closed than if guard cells could take up K+.

B) (6 points)
The fungus secretes a toxin that limits H+-pump activity in plant cell (2 points). This will limit the ability of the cell to hyperpolarize (2 points). Hyperpolarization is necessary to create an electrical force stronger than the force from the concentration gradient (higher K+ inside the cell that outside) to cause allow K+ flux (2 points). This is important in either root hair cells or guard cells.
OR
The fungus secretes a toxin that blocks the K+ channel on the membrane (2 points). This will increase resistance to K+ movement into the cell (2 points), decreasing K+ flux (decreasing the rate of K+ movement) (2 points).

Week 9
Question 1:
(16 points) For the growing leaf cells to expand, they must take up water. Their source of water is the xylem, which is also supplying water for transpiration. As transpiration continues during the day the water potential of the xylem goes lower and lower (becomes more negative). Assuming that high wall extensibility is maintained, explain the mechanism that leaf cells can use to maintain a high elongation rate while xylem water potential decreases (becomes more negative) during the day. Use a flow diagram starting with "Activate more H+ pumps" and ending with "cell elongation continues". For arrows use –cause-->

Key 1: (16 points; 2 points per line not included in the question; students can combine lines and receive full credit; this flow diagram has a split at the top and comes together at the bottom; students may indicate that accurately in a multitude of ways and receive full credit)
Increase H+ pump activity (activate more H+ pumps)--causes two series of things to happen-->
--causes--> cell to hyperpolarize
--causes--> V-K+ to open
--causes--> K+ to enter the growing cell down electrochemical gradient
AND
Increases H+ gradient outside the cell
--causes--> more solutes to enter the growing cell through H+/solute cotransporters
--Both of these cause--> decrease in solute potential (hence decreasing the water potential) of the cell
–causes--> water to move into cell
–causes--> increases/maintains turgor pressure of cell

--causes--> cell elongation to continue

Question 2:
(18 points) The pH of the apoplast of a growing cell decreases.
A) What hormone is involved with the pH change?
B) How does the hormone impact the pH of the apoplast of the cell once it enters the cell? Use flow diagram to answer. For arrows use –cause-->

Key 2: (12 points total)
A) Auxin (2 points)
B) (10 points; 2 points per line; students can combine lines and receive full credit)
Auxin in cell binds to a receptor
--causes--> Auxin+receptor increase SAUR production
--causes--> SAUR decreases (inhibits) phosphatase activity
--causes--> More H+ pumps are active
--causes--> lower pH in the apoplast (or concentration of H+ in apoplast increases)

Question 3:
(10 points) A mutant cucumber plant produces twice as many expansions than a normal plant. What impact will this have on stem elongation rate? Defend your answer.

Key 3: (10 points)
Acidic pH (1 point) in apoplast (or cell wall) (1 point) will activate twice as many (or at the very least more) expansins (2 points). The increased number of expansins will "unzip" more H-bonds (2 points) in between cell wall fibers/polymers (1 point), thereby increasing cell wall extensibility (2 points) and stem elongation rate (1 point).

Student could add more information about how the H+ pump impacts other processes involved in cell expansion (e.g., solute/turgor pressure) but they do not need to.

Week 10:
Question 1:
(10 points) You drop a cucumber seedling on the floor in lab (it is now horizontal to the floor). The next day the shoot is growing up, against gravity.
A) Predict which side of stem cells will PIN proteins be on.
B) How does the movement of PIN proteins lead to the stem bending away from the floor?

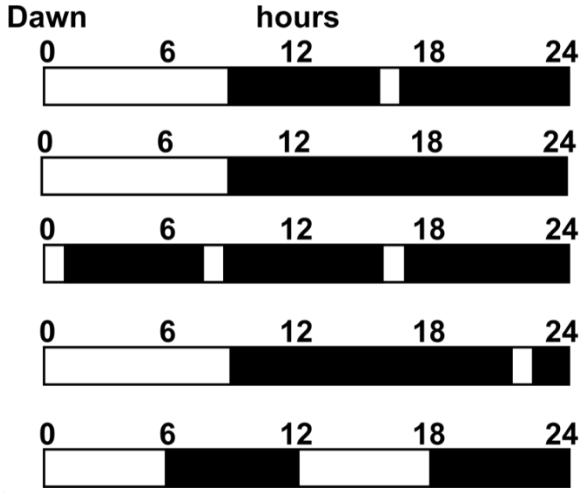
Key 1: (10 points total)
A) The side of the gravity vector (the side the floor is on) (2 points).
B) Auxin can only leave cells via PINs (2 points) so auxin tends to accumulate on the side of the shoot PINs are on (the side on the floor) (2 points). The higher levels of auxin near the floor lead to increased cell elongation on that side of the stem (2 points), causing the stem to bend up away from the floor (2 points).

Question 2:
(12 points) You have phytochrome mutants that are missing the autophosphorylation capacity necessary to convert to Pfr. You unintentionally mixed seeds of phytochrome mutants with wild type plants. Now you would like to isolate the phytochrome mutants from the mixed seed populations so you could breed them separately. Remember, phytochrome is synthesized in the Pr form.

You decided to analyze the stem elongation phenotype to separate the phytochrome mutants.
A) Under which light condition should you grow the plants to be able to tell the mutants from the wild type plants: Red, Far Red or Blue light?
B) Under that condition, would expect that the mutants would be taller or shorter than wild type seedlings?
C) Explain your reasoning.

Key 2: (12 points total; students may phrase C a different way, but must include all the points indicated)
A) Red light (2 points)
B) Taller (2 points)
C) Due to its inability to autophosphorylate, phytochrome in the mutant is always in the Pr form (regardless of light condition) (2 points) and is always elongating quickly (2 points).
The wildtype phytochrome autophosphorylates to the Pfr form (2 points) and will not elongate quickly ONLY in red light (2 points).

Question 3:
(18 points) CONSTANS mRNA is high between 12 and 18 hours after Dawn in a certain plant species of Short-day plant. How many conditions shown in the diagram will induce flowering? Explain why flowering would occur in those treatments and NOT in the others.



Key 3:
Short-day plants would flower in two conditions, the 2nd and 4th (2 points).
In those conditions, CONSTANS (CO) protein would be low (2 points)
because when CO mRNA was high (between 12 and 18 hours) (2 points)
most phytochrome was in the Pr form as there was not a lot of light (specifically red light photons) to convert it to Pfr (2 points)
and Pfr is what causes CO protein to be stabilized (2 points).
Without CO to inhibit it, FT was high in these two conditions (in short-day plants), initiating flowering (2 points).
In the other three conditions, light (and hence Pfr) is coincident with high CO mRNA (2 points)
and CO protein is stabilized (2 points)
and inhibits FT production and flowering in short-day plants (2 points).