1. The Greek philosopher Aristotle hypothesized that the brain was
   a) A radiator for cooling the blood.*
   b) The seat of the soul.
   c) The organ of sensation.
   d) The center of intellect.
   e) An organ used to move body parts.

2. Paul Broca’s contribution to the understanding of nervous system function included
   a) The creation of the science of phrenology.
   b) Providing strong evidence for localization of function in the human cerebral cortex.*
   c) Providing evidence from the study of birds that the cerebellum is involved in controlling movement.
   d) Brain surgery could remove an area of the brain that is damaged and causing hallucinations.
   e) More than one of the above is correct.

3. All of the following are types of glia EXCEPT
   a) Astrocytes
   b) Ependymal cells*
   c) Oligodendroglia
   d) Schwann cells
   e) Micr...glia

4. The “neuron doctrine”
   a) Was proposed by Golgi.
   b) Was supportive of the reticular theory.
   c) Was refuted by Cajal.
   d) States that the neurites of neurons are not continuous with one another.*
   e) Described a primitive way of communications based on a simple reflex arc described by Descartes.

5. The three components of the cytoskeleton of a neuron are
   a) Actin, myosin, troponin.
   b) Microtubules, neurofilaments, neurofibrillaries.
   c) Neurofilaments, actin, microtubules * (microfilaments are made of actin molecules).
   d) Golgi apparatus, neurofilaments, neurotubules.
   e) Neurofilaments, neurotubules, microfilaments.

6. This organelle is a major site of synthesis of proteins destined for the plasma membrane.
   a) Rough ER.*
   b) Smooth ER.
   c) Golgi apparatus.
   d) Mitochondrion.
   e) Nucleolus.

7. Which of the following cells would be likely to myelinate an axon in your leg?
   a) Microglia
   b) Astrocytes
   c) Oligodendroglia
   a) Kinesin; dynein*  
   b) Dynein; kinesin  
   c) Microtubule; microfilament  
   d) Microfilament; microtubule  
   e) None of the above

9. Postmortem examination of the brain of an Alzheimer’s disease patient reveals the presence of neurofibrillary tangles in certain areas. These are believed to be caused by
   a) Entanglements of rough ER  
   b) Neurofilament degradation  
   c) Degeneration of microfilaments  
   d) Disregulation of beta-amyloid  
   e) Disregulation of a microtubule-associated protein (MAP) *

10. Which of the following is NOT thought to be a function of astrocytes?
    a) Phagocytosis  
    b) Metabolic transport of nutrients necessary for normal neuronal function  
    c) A component of the blood brain barrier  
    d) Regulation of Ca\(^{2+}\) concentrations around the synapse  
    e) Transportation of neurotransmitter through the blood brain barrier *

11. Which of the following functions does the neurolemmal cells perform that astrocytes do not?
    a) Phagocytosis  
    b) Responds to neuronal injury  
    c) A component of the blood brain barrier *  
    d) Supports developmental processes  
    e) None of the above

12. Which of the following is true about microglia
    a) They regulate the chemical content of the extracellular space surrounding neurons  
    b) They are responsible for myelinating axons  
    c) They are able to perform phagocytosis within the CNS *  
    d) They are important for providing structural support for neurons  
    e) Actually, research has not been able to reveal their functions yet.

13. You discover an alien life form that uses the same ions as Earth life forms to generate membrane potentials. The concentrations of these ions, however, are very different from those found inside and outside of neurons in Earth creatures. Given the following ionic concentrations (inside: 35 mM K\(^+\), 80 mM Na\(^+\); outside: 70 mM K\(^+\), 40mM Na\(^+\)), the E\(_{\text{Na}}\) will be ____ and E\(_{\text{K}}\) will be ____. (RT/zF = 57.5)
    a) 17.3 mV, 17.3 mV  
    b) 17.3 mV, - 17.3 mV  
    c) -17.3 mV, 17.3 mV *  
    d) - 17.3 mV, -17.3 mV  
    e) We do not have enough information to determine E\(_{\text{ion}}\).
14. We can infer that the resting membrane potential of our alien neuron is _____________
   a) Negative
   b) Zero
   c) Positive
   d) Going to alter the threshold for the action potential.
   e) We can’t infer anything about the resting membrane potential without a little more information*

15. Assume that for a neuron, \( E_K = -80 \text{ mV} \) and the resting membrane potential is \(-65 \text{ mV} \). If the membrane potential were suddenly brought to \(-100 \text{ mV} \), which way would potassium flow across the membrane?
   a) Potassium would flow out of the cell.
   b) Potassium would flow into the cell.*
   c) There would be no net flow of potassium into or out of the cell.
   d) Actually there would be an influx of potassium followed by an efflux as the delayed rectifier current would remain open longer than necessary.
   e) Potassium ions would be totally confused and stampede into the mitochondria.

16. Which of the following best explains why an action potential normally travels in one direction down an axon?
   a) Afterhyperpolarization.
   b) Overshoot.
   c) Absolute refractory period.*
   d) Threshold.
   e) None of the above since the action potential normally travels both directions along an axon.

17. During the falling phase of an action potential, the voltage-gated sodium channels are mostly __________, the delayed rectifier potassium channels are mostly __________.
   a) Inactivated; open*
   b) Inactivated; closed
   c) Open; closed
   d) Closed; open
   e) Deinactivated, open

18. Suppose a neuron was selectively permeable only to \( \text{Na}^+ \) ions. What would happen to the membrane potential of this cell if \( \text{K}^+ \) channels then opened?
   a) \( V_m \) would overshoot
   b) Nothing would happen to the membrane potential
   c) \( V_m \) would depolarize
   d) \( V_m \) would hyperpolarize*
   e) The cell would fire an action potential

19. All of the following are true about the equilibrium potential of an ion EXCEPT
   a) It depends on the concentration of the ion inside and outside the neuron.
   b) It depends on the membrane conductance to that ion.*
   c) It is the voltage at which diffusional and electrical forces on the ion are equal yet opposite.
   d) It depends upon the positive and negative charges on the inside and the outside of the membrane.
   e) There are no exceptions; all of the above are true.
20. If you instantly destroyed all of the sodium/potassium pumps in your neurons, 
a) They could no longer fire action potentials.  
b) They would depolarize and die within seconds.  
c) They could fire action potentials for a while but would eventually depolarize and die. *  
d) They would be unaffected.  
e) They would become hyperpolarized.

21. All of the following will increase the speed with which an axon conducts action potentials EXCEPT  
a) Having greater distance between the nodes of Ranvier.  
b) Increasing the diameter of the axon.  
c) Myelinating the axon.  
d) Increasing the density of the Na\(^+\) channels at the axon hillock. *  
e) All of the above will increase the speed of the action potential.

22. The “rising phase” of the action potential is caused primarily by the influx of  
a) Excitatory transmitter into the nerve cell through transmitter-specific channels.  
b) Sodium into the nerve cell through voltage-gated channels.*  
c) Sodium into the nerve cell through transmitter-gated channels.  
d) Potassium into the nerve cell through transmitter-gated channels.  
e) Potassium into the nerve cell through voltage-gated channels.

23. You observe an action potential from a typical neuron; then you apply a toxin that blocks delayed rectifier voltage-gated potassium channels and observe the effects. What characteristics of the action potential would be changed?  
a) Duration of the action potential  
b) Undershoot (afterhyperpolarization)  
c) Resting membrane potential  
d) Self-propagation  
e) Both a and b*

24. Why is I\(_K\) greater at the height of an action potential than at rest?  
a) Because delayed rectifier channels are open.  
b) Because V\(_m\) – E\(_K\) is greater at the height of an action potential.  
c) Because E\(_K\) becomes more positive.  
d) Because E\(_K\) becomes more negative.  
e) Both a and b*

25. Increasing extracellular K\(^+\) would lead to  
a) Depolarization of the membrane (V\(_m\) becomes more positive).*  
b) Depolarization of the membrane (V\(_m\) becomes less positive).  
c) Hyperpolarization of the membrane (V\(_m\) becomes more positive).  
d) Hyperpolarization of the membrane (V\(_m\) becomes less positive).  
e) Actually the Goldman equation would predict no change in V\(_m\) due to compensation.
26. Increasing intracellular Na\(^+\) in a typical neuron would have what effect on \(E_{Na}\)?
   a) \(E_{Na}\) would become more positive.
   b) \(E_{Na}\) would become less positive.*
   c) \(E_{Na}\) would stay the same.
   d) \(E_{Na}\) would become less positive which in turn would increase the resting membrane potential.
   e) There is not enough information given to determine the effect on \(E_{Na}\).

27. Typically, action potentials do not travel to the synaptic terminal and then rebound and propagate back to the soma. Which of the following is responsible for ensuring that action potentials only travel down the axon in one direction?
   a) Absolute refractory period.*
   b) Saltatory conduction.
   c) The length constant.
   d) Axoplasmic transport.
   e) The delayed rectifier current.

28. If an axon at resting membrane potential were exposed to tetrodotoxin (TTX), the result would be
   a) An action potential.
   b) A very slow depolarization.
   c) A rapid hyperpolarization.
   d) A slow hyperpolarization.
   e) TTX will have little or no effect on the resting membrane potential.*

29. A person ingests a drug that alters voltage-gated sodium channels such that they no longer inactivate. What would be the consequences of being exposed to such a drug?
   a) The threshold for firing action potentials would decrease.
   b) The threshold for firing action potentials would increase.
   c) Action potentials would occur at a higher frequency.
   d) The membrane would not repolarize rapidly after an action potential.*
   e) The overshoot of the action potential would now be increased.

30. Which of the following is most closely related to the release of neurotransmitter from the presynaptic terminal?
   a) Concentration of calcium in the presynaptic terminal.*
   b) Membrane potential in the presynaptic terminal.
   c) Concentration of sodium in the presynaptic terminal.
   d) Reversal potential in the presynaptic terminal.
   e) The presence of Na\(^+\) channels on the presynaptic terminal.

31. Dr. Starbucks discovers a new chemical in the brain, called jumpy-addictive-vigorous-amine (JAVA for short). To classify JAVA as a classical neurotransmitter, Dr. Starbucks must demonstrate all of the following EXCEPT
   a. It must be synthesized in the neuron and stored in the presynaptic terminal.
   b. Stimulating the presynaptic neuron must cause the release of JAVA into the synaptic cleft.
   c. JAVA must be stored in neighboring glial cells.*
   d. Applying JAVA to the postsynaptic cell should elicit a response.
   e. B and C are criteria for a classical neurotransmitter, but A or D are not.
32. A presynaptic neuron fires at 10 action potentials (APs) per second, and the postsynaptic cell does not fire an AP. When the same presynaptic neuron fires at 20 APs per second, however, the postsynaptic cell fires. This is an example of
   a) Temporal summation*
   b) Spatial summation
   c) Shunting inhibition
   d) Axonal summation
   e) Presynaptic summation.

33. Inhibitory postsynaptic potentials (IPSPs)
   a) Are always due to the opening of potassium channels
   b) Occur only at the soma
   c) Do not spatially summate
   d) Keep a neuron away from threshold*
   e) A and B are correct but not C or D

34. Which of the follow is the fastest form of synaptic communication?
   a) Chemical
   b) Neuromuscular
   c) Axodendritic
   d) A xoaxonic
   e) Gap junction *
Briefly define or describe 3 of the following 5 (4 points each):

1. PSI (give me the name and function) (text and lecture)
   Presynaptic inhibition - presynaptic hyperpolarization which leads to decreased Ca2+ influx and less exocytosis of neurotransmitter. Can be result of hyperpolarization at axoaxonic synapse.

2. Dendritic spines (text)
   A small sac of membrane that protrudes from the dendrites of some cells and receives synaptic input.

3. Channel conductance
   The ease with which an ion is allowed to cross a membrane through an ion channel. Unit of measure will be siemens (S). This may be a relative measure of the number of channels open, \( gK \) = number of K⁺ channels open.

4. Goldman equation
   A mathematical relationship used to predict/calculate membrane potential (Vm) from the concentrations and relative permeabilities of membrane for 2 or more ions. Formula on page 68.

5. Pore loop
   A portion of a polypeptide contributing to the structure of an ion channel. Usually several (e.g., 4) pores are located within the channel pore. Its critical function is to select the ions that will flow through the channel pore.

Essay (20 points):
You have discovered a new type of neuron in a recently discovered fish species and you need to determine which ions are responsible for its action potential. You decide to use the voltage clamp method for your experiments.

1) What is the voltage clamp method and what does it tell you?

   Method in which the experimenter can “clamp” or hold the Vm constant and measure membrane ion currents at different voltages.

   [Many mistook this as patch clamp in which a single ion channel is studied. This is different from placing an electrode inside the cell body (intracellular recording), axon or dendrite where you will be recording from POPULATIONS of channels. You can perform voltage clamp experiments with either patch clamp or intracellular recording.]

2) How would you use this method to determine if Na⁺ or K⁺ is contributing to the action potential?

   This answer could be approached several ways but the most straight forward was to determine if/which ion was responsible for each FUNDAMENTAL characteristic of an action potential. Specifically, which ion exhibits a voltage-related threshold. Which ion is responsible for the rising phase (depolarization) of the AP. Which ion is responsible for the repolarization of the AP. Which was responsible for the RMP. Most likely you would step Vm in increments (e.g., 20 mV) from some very hyperpolarized point (-100 mV) to some very depolarized point (e.g., +160 mV) while manipulating either concentrations of each ion or the conductance of Na⁺ or K⁺ channels. Some of you suggested that you would block one channel while measuring the current of the other were altering conductance (although most did not say this).
State assumptions somewhere: channels are voltage-gated, with thresholds, each channel is selective for Li⁺ or Ca²⁺.

If an ion is responsible for the action potential, then use voltage clamp to see if the current flow of the ion matches the characteristics of the action potential while you hold the concentrations of that ion constant on the inside and outside of the axon. For example, if Ca²⁺ is the ion responsible for the spike, then you would predict that there would be a current flow associated with a threshold. Thus you will not see any current flow until you step the Vm to above the threshold. You should also see a current flow that can account for the size of the action potential Vm (all-or none). That is the current flow has to be great enough to approach its equilibrium potential.

If your new neuron is like a “standard” neuron, you will find that one of the ion currents is more important for initiation and size of the action potential and that the other ion current will be more important for hyperpolarization. One of the ions will cause the depolarization by its inward current and the other ion will be responsible for the hyperpolarization through an outward current. You only had to describe the parallels between Na⁺, K⁺ and the two ions in the question.

You will not get full credit for simply saying that. You HAD to explain what you expected to see for Li⁺ or CA 2+ currents, based on your knowledge of how Na⁺ and K⁺ currents drive the electrical characteristics of the AP. Voltage clamp method will allow you to determine which ion has an outward flow that will be responsible for the hyperpolarization after the initial depolarization.

Options considered for credit:
Which role for the AP you assigned to each ion was not important. One of the ions, of course, will contribute the initiation of the action potential and the other will contribute to the hyperpolarization. If the ion contributes to the hyperpolarization, its current will drive Vm towards the E of that ion. You could further test this by changing the concentrations of the ion inside and out. This will alter the rate and the degree to which it of hyperpolarizes the membrane (back to RMP) You would need to change the concentration of one ion while holding the second (e.g., Li⁺) constant. This changes the equilibrium potential and therefore the size of the action potential or RMP.

You could also use either substitute ions (substituting 1 at a time) that will not go through the channels but will maintain the electrical gradient or you could use a poison or a drug that blocks conductance of one of the two types of channels, while measuring the remaining current flow.

3) How can this method tell you if there is an inactivation gate involved in the action potential?

Interestingly, many of you who did not get (1) managed to answer this one correctly.

An inactivation gate closes the channel and stops ion current shortly after the channel is opened. It does so even when the Vm remains above threshold such as when you have the Vm clamped or holding Vm at a particular voltage. If there is no inactivation gate, then the ion current will continue as long as you have the Vm above the threshold for the channel.

The anatomy answers can be found on the appropriate images in Chapter 7. 1 point per correct answer.