1. a) If the value of component A becomes smaller, the value of component B also becomes smaller because the two components are connected by a sign-preserving arrow (i.e., there is a + sign on the arrow).

b) Yes; if the value of component D becomes smaller, the value of component E will increase because the two components are connected by a sign-inverting arrow (i.e., there is a - sign on the arrow).

c) The loop that connects components A, B, C, D, E, and F is a positive feedback loop because it includes two sign-inverting arrows.

d) Yes; the loop that connects components B and C is a negative feedback loop because it includes one sign-inverting arrow.

PLEASE NOTE: You must consider only one loop at a time. The two loops in this diagram both include components B and C, but they are two separate loops. Remember that you it makes no sense to go backwards in a loop; you must proceed only in the directions in which the arrows point.

2. a)

![Diagram](image)

b) The system produces positive feedback because the loop has two negative effects: (1) the air conditioner causes a decrease in temperature; and (2) when the temperature decreases, the output of the thermometer increases. [This increased reading of the thermometer keeps the air conditioner on, even when the temperature is colder that the set-point temperature.]
3. a) [You need you calculator to solve for the log values; you would get full credit if you just set up the equations properly.]

\[ E_{Na} = 61 \log \left( \frac{150}{10} \right) \text{ mV} = 61 \times (1.176) \text{ mV} = +71.7 \text{ mV} \]

\[ E_K = 61 \log \left( \frac{3}{112} \right) \text{ mV} = 61 \times (-1.572) \text{ mV} = -95.9 \text{ mV} \]

\[ E_{Cl} = -61 \times \log \left( \frac{[Cl^-]_{out}}{[Cl^-]_{in}} \right) = -61 \times (1.342) = -81.9 \text{ mV}. \]

Note: \( E_{Cl} \) could also be calculated as \( 61 \log \left( \frac{4}{88} \right) \text{ mV} = 61 \times (-1.342) = -81.9 \text{ mV} \)

b) Depolarizations in action potentials approach (but do not usually reach) \( E_{Na} \). Therefore, during an action potential \( V_m \) may become as inside-positive as +71.7 mV, but no greater than this.

[In fact, most action potentials are over too fast to allow the membrane to become this positive, so at the peak of the action potential the transmembrane potential is likely to be somewhat less positive than this.]

NOTE: If the \( V_m \) were somehow made more positive than +71.7, the driving force on \( Na^+ \) would push it out of the cell, rather than into the cell and pull the \( V_m \) toward \( E_{Na} \). Because \( Na^+ \) moves in one direction if \( V_m \) is more negative than \( E_{Na} \) and in the opposite direction if \( V_m \) is more positive than \( E_{Na} \), \( E_{Na} \) is also called the \textit{reversal potential} for \( Na. \]

c) The after-hyperpolarization of an action potential approaches (but does not usually reach) \( E_K \). During an action potential, \( V_m \) is made more negative by an outward flow of \( K^+ \), so the \( V_m \) could reach -95.8 mV (\( E_K \)), but no greater.

[NOTE: -95.8 mV is the reversal potential for \( K^+ \) in this case: if \( V_m \) were forced to be more negative than -95.8 mV, \( K^+ \) would enter the cell, rather than leaving it, and \( V_m \) would be pulled toward \( E_K \).]

d) If the external \( Na^+ \) concentration were cut in half, \( E_{Na} \) would become:

\[ E_{Na} = 61 \log \left( \frac{75}{10} \right) \text{ mV} = 61 \times 0.875 \text{ mV} = +53.4 \text{ mV} \]

and the most positive value that could be reached by the \( V_m \) during an action potential would be +53.4 mV. Therefore, the amplitude of the action potential would likely be reduced. You cannot predict that it \textit{would} for sure be reduced, because \( V_m \) doesn't necessarily reach its \( E_{Na} \) during the course of any action potential.

e) \( E_K \) would equal \( 61 \log \left( \frac{20}{112} \right) \text{ mV} = 61 \times (-0.748) \text{ mV} = -45.6 \text{ mV} \); that is, \( E_K \) would shift to a less inside-negative value. Because the resting potential in many cells depends most strongly on \( K^+ \), this shift in \( E_K \) would make cells very depolarized compared to their
normal resting potential. If you knew relative ionic permeabilities, you could also solve the Chord Conductance equation to determine the equilibrium potential for these new concentration values. (The Chord Conductance equation is a better predictor of the resting potential than is the Nernst equation, because it takes into account the effect of other permeating ions besides $K^+$. Notice, however, that although the Chord Conductance equation would allow you to predict $V_m$, you still would have to measure the the relative ionic conductances, which is more difficult than measuring $V_m$ directly.)

4. a. Yes, because you know $[Na^+]_o$ and the value of $E_{Na}$, you can use the Nernst equation to solve for $[Na^+]_i$:

$$E_{Na} = 0 = \frac{2.303}{z} \log \left( \frac{[Na^+]_o}{[Na^+]_i} \right) = 61 \log \left( \frac{[Na^+]_o}{[Na^+]_i} \right)$$

For $(\log 100 / [Na^+]_i)$ to equal 0, $X = 100$ mM, the same as $[Na^+]_o$.

b. Of the ions listed, the only one that could produce an overshoot is $Ca^{++}$, because it has an equilibrium potential more inside-positive than +30 mV. [The usual ion responsible for the overshoot—$Na^+$—has only a 0 mV equilibrium potential.]

5. a) By far the majority of neuronal action potentials in mammals (and probably in most other animals, as well) are based upon the action of voltage-gated $Na^+$ channels. Therefore, TTX will shut down activity in the brain.

[Note: A few neurons produce action potentials via alternative mechanisms, for example, $Ca^{++}$-based depolarizing phases. These cells would be unaffected by the presence of TTX. In addition, some voltage-gated $Na^+$ channels are insensitive to TTX, but not many of them are.]

b) By blocking voltage-gated $K^+$ channels, TEA would slow down the repolarizing phase of the action potentials in neurons. For sure, the action potentials would be broader (i.e., longer-lasting), and they might have a larger amplitude, depending on the relative contributions of the $K^+$ channels and the inactivation of $Na^+$ channels to the turning off of the depolarizing phase of action potentials (i.e., the size of the over-shoot) in a given neuron.
6. IMPORTANT: Remember the convention for plotting currents: **inward-going currents of positive ions is plotted downward**, and **outward-going currents of positive ions is plotted upward**.

a) **Suprathreshold stimulus at arrow:**

b)  

c)
7. Why is the equilibrium potential for an ion channel also called its “reversal potential”?

When \( V_m \) is equal to \( E_X \) for any ion \( X \), no current is carried by \( X \) even if there is a huge conductance for that ion. If \( V_m \) is more positive than \( E_X \), opening the channel for \( X \) causes a hyperpolarization, moving the membrane potential toward \( E_X \). If \( V_m \) is more negative than \( E_X \) opening the \( X \) channels again causes \( V_m \) to move toward \( E_X \), which causes the cell to depolarize. So, the polarity of the response reverses as the membrane potential crosses the equilibrium potential.

8. A. Describe temporal and spatial summation.

Temporal summation: multiple action potentials propagated along a single pre-synaptic neuron arrive in rapid succession at the synaptic terminals. To summate, each successive action potential release transmitter before the postsynaptic effect of transmitter from the previous action potential is over. As a result, the postsynaptic potentials add to produce a PSP that is larger than a single PSP.

Spatial summation: action potentials in several presynaptic neurons arrive at a single postsynaptic neuron within a short time period and produce a larger PSP than any of the presynaptic neurons could have produced alone.

Discussion point: These answers assume that all of the PSPs are either excitatory or inhibitory, and hence the summed PSP is larger than individual PSPs would have been. In fact, both excitatory and inhibitory PSPs will sum spatially and temporally, and if excitatory PSPs are summed with inhibitory PSPs, the resultant shift in membrane potential will be smaller than the individual excitatory PSPs would have been.

B. How can the properties of a threshold and summation make the nervous system more flexible?

Every neuron has a threshold potential and mostly, a single EPSP is not sufficient to bring the \( V_m \) to threshold for an action potential. Temporal and/or spatial summation is usually required to produce action potentials. In the nervous system, the responses of each neuron result from many input neurons acting in concert, and such inputs may vary over time. A particular stimulus may produce an effect one time and no effect the next, depending upon what else is happening in the system.

Discussion point: Modulating the strength of synapses can greatly change the behavior of a network of neurons. Learning usually results from modifying synaptic strengths in some way.
C. What would be the effect on $V_m$ if equal numbers of excitatory and inhibitory postsynaptic channels were to open simultaneously in a postsynaptic neuron, producing an equal amount of excitatory and inhibitory current?

If there were equal excitatory and inhibitory currents—and they had similar conductances—$V_m$ would likely change very little because the effects of the two inputs would balance each other.

D. What would be the effect on $V_m$ if simultaneously many excitatory channels opened and only a few inhibitory channels opened?

$V_m$ would be depolarized.

E. What would be the effect on $V_m$ if simultaneously many inhibitory channels opened and only a few excitatory channels opened?

$V_m$ would be held below threshold.

[Notice that you shouldn’t say that $V_m$ would hyperpolarize. Why?]

9. A. What does it mean when we say that a signal is "all-or-none?" List one kind of signal in the nervous system that is all-or-none.

"All-or-none" means that if a signal occurs at all, it is always the same size and shape. Action potential (although it can be reduced in size if it occurs within the relative refractory period of the previous one).

B. What does it mean when we say that a signal is "graded"? List two signals in the nervous system that are graded.

Graded signals have amplitudes that vary in proportion to the size of the input that they receive.

Synaptic potential and receptor potentials are graded. [In some sense, resting potentials are also graded, in response to changes in external concentrations of ions.]
10. A neuron C receives synaptic input from two other neurons, A and B. Shown below are the responses of neuron C to input from neurons A and B individually, followed by A and B at the same time (A + B), then to a pair of inputs from A at a short interval (A A).

A. Explain how the response to A and B (A+B) does not show summation. Be brief; show any appropriate calculations.

Because A+B is the same size as A and B alone, one of them is likely to be inhibitory, with its reversal potential near the peak of the synaptic potential. Because temporal summation of the responses to two closely-spaced A's produces an action potential, the response to A must be an EPSP.

B. On the diagram, draw the predicted response to stimulating neuron B twice in quick succession (at the times of the two arrows marked “B B” at the end of the recording). Briefly explain.

Because the response to B must be an IPSP with a reversal potential near its depolarized peak (see A above), the two responses to B would not sum, because their peaks cannot go more positive than the reversal potential.