Cell Membrane Transport Processes

Active Transport (Part-II):

Cellular Functions Made Possible by the Na^+- K^+ Pump

Learning Objectives:

- List and describe **Briefly** the cellular functions made easy by Na/K pump.

- Describe the mechanism of secondary active transport and list some examples of sodium coupled transport.

- Describe the possible causes and the clinical significance of deteriorated Na/K pump.

- List the function of Ca^{++} ions in the cell and describe the metabolic effects of inhibition of Na/Ca counter transport.

Cellular Functions Made Possible by the Na^+- K^+ Pump:

1.Electrochemical Function:

a) Resting potential of all cells:

- The sodium/potassium pump keeps our cells electrically charged, like electric cells.
- The negative charge is only found at the inside of cell membrane, but it is very important.
- The negative charge is created by many different ion types (anions) as well as Na and K.
- This is called the ***"resting potential"*** of cells at rest, and gives every cell a polarity.
- The membrane is "leaky" to these ions (especially K), so pump must keep going.

Cellular Functions Made Possible by the Na^+- K^+ Pump:

b) Passive movements of sodium and potassium:

- Every cell membrane also has transport proteins which can carry ions. These are highly specific ***"Na^+ channels", "K^+ channels"*** and ***"Ca^{++} channels".***

- These channels are ***"gated"***, so they can be opened and closed for specific purposes.

- Some are ***"voltage-gated"*** and others are ***"chemical-gated"***.

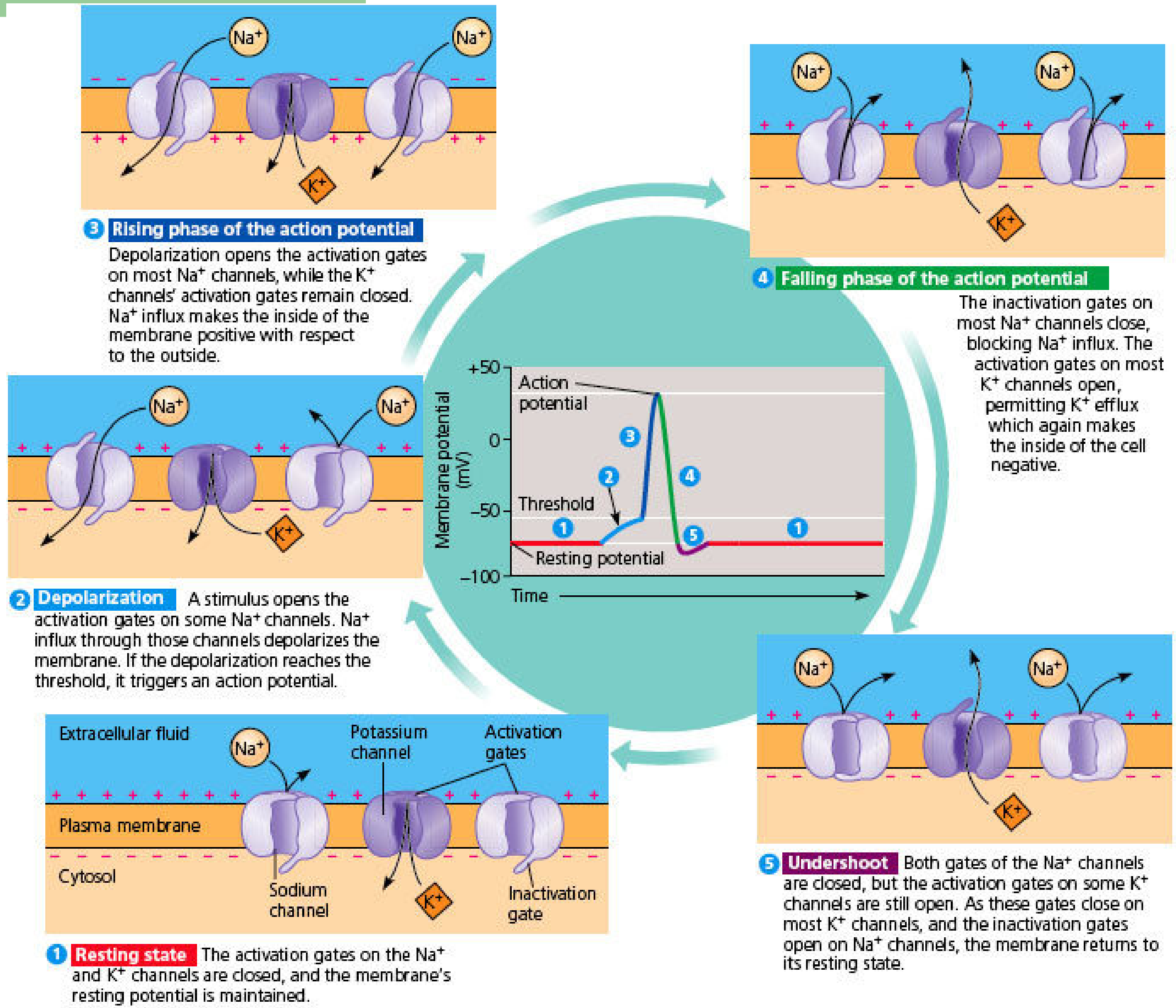
c) Nerve cell function (see the image in the next slide):

- An ***"action potential"*** is propagated when a voltage change causes gates to open. After 2 milliseconds, sodium gates open, causing Na^+ to flood into the cell.

- Half a millisecond later, sodium gates close and potassium gates open. Then potassium gates close, while sodium is pumped out of the cell again.

- By 4 milliseconds, pumps have restored the resting potential, ready for another impulse.

Cellular Functions Made Possible by the Na^+- K^+ Pump:



Action Potential

Cellular Functions Made Possible by the Na^+- K^+ Pump:

2. Energy source for other transport *(Secondary Active Transport):*

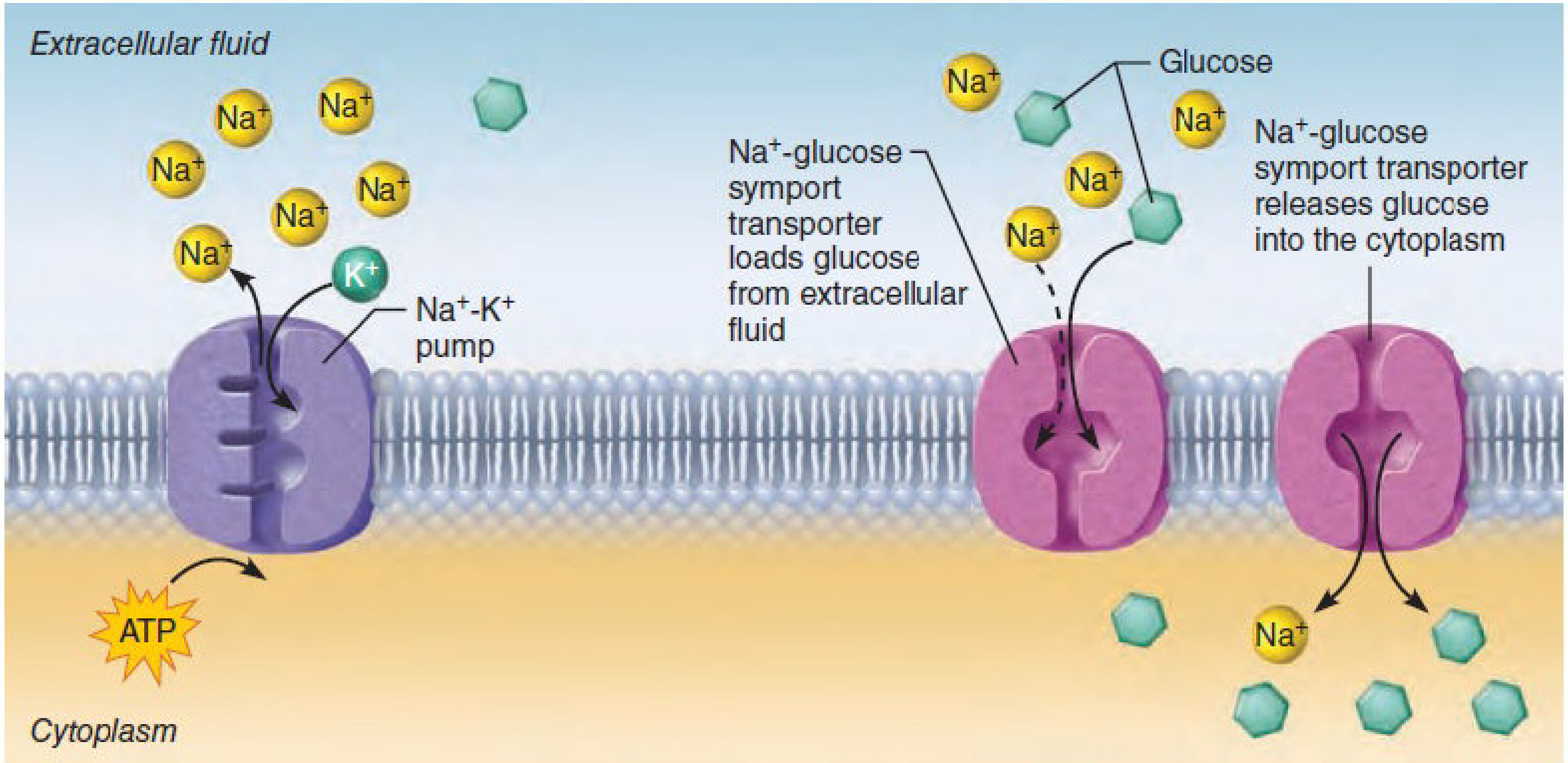
- A single ATP-powered pump, such as the Na-K pump, can indirectly drive the **secondary active transport of several other solutes.**
- By moving sodium across the plasma membrane against its concentration gradient, the pump stores energy (in the ion gradient).
- Then, just as water pumped uphill can do work as it flows back down (to turn a water wheel, for instance), a substance pumped across a membrane can do work as it leaks back, propelled "downhill" along its concentration gradient.
- In this way, as sodium moves back into the cell with the help of a carrier protein, other substances are "dragged along," or cotransported, by the same carrier protein (symport system).
- Some sugars, amino acids, and many ions are cotransported via secondary active transport into cells lining the small intestine.

Examples of sodium coupled transport:

a) Sodium/Glucose cotransport:

- Sodium enters the cell passively, through a sodium channel that opens to allow this.
- This particular type of sodium channel can also carry glucose.
- The energy of this exergonic sodium movement, powers the glucose movement.
- The glucose movement is against its concentration gradient, = ***"active transport".***
- ***This is used for feeding the brain, when your blood glucose is low.***

Examples of sodium coupled transport:



① **Primary active transport**
The ATP-driven Na^+-K^+ pump stores energy by creating a steep concentration gradient for Na^+ entry into the cell.

② **Secondary active transport**
As Na^+ diffuses back across the membrane through a membrane cotransporter protein, it drives glucose against its concentration gradient into the cell.

Secondary active transport is driven by the concentration gradient created by primary active transport.

Examples of sodium coupled transport:

b) Sodium/calcium countertransport:

- Sodium enters the cell passively, through a sodium channel that opens to allow this.
- This movement is linked with a calcium ion channel.
- The energy of exergonic sodium movement, powers calcium movement *out of the cell.*

Note:

- ✓ *Sodium enters the cell passively, while simultaneously providing the energy for calcium to leave the cell actively (against its concentration gradient).*
- ✓ *If calcium ions were to accumulate in cells, they would crystallize out, and that would interfere with normal cell function. It happens to some extent as we age, causing unwanted calcification of soft tissue.*

Importance of the Na/K Pump:

- It is calculated that the ***Na/K pump uses one third of our resting energy expenditure.*** There is no other single process that uses so much of our energy.

- Sodium/potassium pump function is ***reduced by 40% in diabetics and hypertensives.***

- ***Mg^{++} ions are a cofactor for the Na/K pump***, and ***60% of Americans are Mg deficient.***

Na/K Pump-Clinical Significance:

a) Na/K pumps can deteriorate, due to high-sodium, low-magnesium diet:

- **Magnesium** is ***only found in green leafy vegetables***, whole seeds and whole grains.
- ***Many Americans do not eat these foods, so they are magnesium-deficient.***
- So, lacking Mg^{++}, an essential cofactor, Na/K pump function can be compromised.
- Too much sodium (in salty food) may over1oad the Na/K pump, and weaken it that way.

(Note: this inhibition is only slight - a strong Na/K pump inhibition would kill us!)

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b) Na/K pump inhibition causes inhibition of Na/Ca counter transport:

- The mechanism we discussed on the previous slides, can't. work if the Na/K pump is inhibited. This causes calcium to build up inside cells, causing calcification of soft tissue.

- Dietary calcium ends up in soft tissue, with less in our bones $\longrightarrow$ **osteoporosis.**

Na/K Pump-Clinical Significance:

c) Functions of calcium ions in cells: There are several cellular mechanisms that can only occur because calcium ions are allowed to flood into the cell and trigger these mechanisms. However, they cannot occur repeatedly unless the calcium ions are pumped out again after each stimulus; These functions are as follows:

- **Muscle contraction** is initiated by opening of calcium gates, for calcium to flood into the cell and cause the ***actin and myosin*** to interact. Calcium must be pumped out again after this, for repeated or maintained muscle contraction.

- **Calcium acts as a second messenger** within cells. Hormones such as ***adrenalin*** function by increasing the intracellular concentration of Ca^{++}. This "fight or flight" hormone acts in the short term, and the Ca^{++} must be removed to return to normal.

- **Secretory processes** are initiated by opening of calcium gates, for calcium to flood into the cell and cause ***exocytosis*** (discussed in the next lecture). Again, *calcium must be pumped out again after this, for repeated secretion.*

Na/K Pump-Clinical Significance:

d) Metabolic effects of inhibition of Na/Ca counter transport:

Elevated Ca^{++} levels inside cells causes **HEART DISEASE**, by making the following things happen:

- ***Smooth muscle tension in arteriole*** walls, increasing blood pressure.

- ***Increased response to stress***, causing more contraction of arterioles, and raising blood pressure even further, contributing to coronary risk.

- ***Insulin resistance*** $\longrightarrow$ hyperinsulin secretion (but tissues cannot use it because of resistance) $\longrightarrow$ diabetes mellitus, which in turn increase cholesterol and fatty acid synthesis, which raises coronary risk even further.