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Similarities in Portable Energy Form in Hydropower Dams and The Electron Transport Chain

Alana Franklin

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Similarities in Portable Energy Form in The Hoover Dam and Electron Transport Chain

Alana Franklin
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Rule-to-Build-By:

Gradients concentrate energy that can be converted into a portable form.

What:

The Electron Transport Chain generates Adenosine Triphosphate (ATP) by using the electrochemical gradient to create portable energy, ATP. This upholds the rule-to-build-by as the gradient concentration energy, proton, be converted from potential energy to portable energy in the form of ATP.

Hydropower dams generate electrical energy through the process of using water potential which uses gravitational gradient to generate hydroelectric power. The electrical power is transported to areas by electrical wires. This upholds the rule-to-build-by as the gradient concentration energy, water, to be converted to electrical energy which is carried through by electrical wires.

How:

Mitochondria are double membrane organelles with an outer membrane permeable to solutes and an inner membrane harboring the electron transport chain complexes. The electron transport chain pumps protons from the mitochondrial matrix into the intermembrane space to generate a maximal proton-motive force across the inner mitochondrial membrane as seen in Figure 1 (Kent, n.d). The H+ buildup in the intermembrane space is due to the flows of high energy electrons from NADH and and $FADH_2$ that is passed along an electron transport chain (Lane, 2010). The number of positively charged H+ in the intermembrane of the Mitochondria is greater than the number of positively charged H+ in the matrix. This result in a relative negative charge in the matrix, and a positive charge in the intermembrane space as seen in Figure 1. The difference in charges causes a voltage to exist across the membrane. Voltage is electrical potential energy that is caused by a separation of opposite charges, in this case across the membrane. The voltage across a membrane is the membrane potential (Wilkin *et al,* 2014). The membrane potential generates a pH gradient across the inner mitochondrial membrane with the pH higher in the matrix than in the intermembrane, where the pH is generally close to 7. The pH gradient reinforces the effect of the membrane potential. Together, the change in pH and the change in voltage constitute an electrochemical proton gradient as seen in Figure 1 (Alberts *et al,* 2002). As the gradient builds up, more and more energy is required to push protons across from matrix space outward. When the amount of energy required to push protons reaches 69.5 kJ/mole, electron transport has to stop. In fact, the second law of thermodynamics requires that electron transport stop *before* the gradient builds up to that point. If there was no way of draining energy from the system, electron transport could not continue despite the presence of adequate substrate. However, a mitochondrion is always in a steady state of respiration, in which the energy lost by processes that dissipate the gradient is constantly replaced by electron transport (Chemiosmotic Gradient, n.d). The electrochemical proton gradient across the inter mitochondrial membrane is used to drive ATP synthesis in the process of oxidative phosphorylation. The device that makes this possible is a large membrane-bound enzyme called ATP synthase. This enzymes creates a hydrophilic pathway across the inner mitochondrial membrane that allows protons to flow down their electrochemical gradient. As these ions thread their way through the ATP synthase, they are used to drive the energetically unfavorable reaction between ADP and Pi to create ATP (Berg *et al,* 2002).

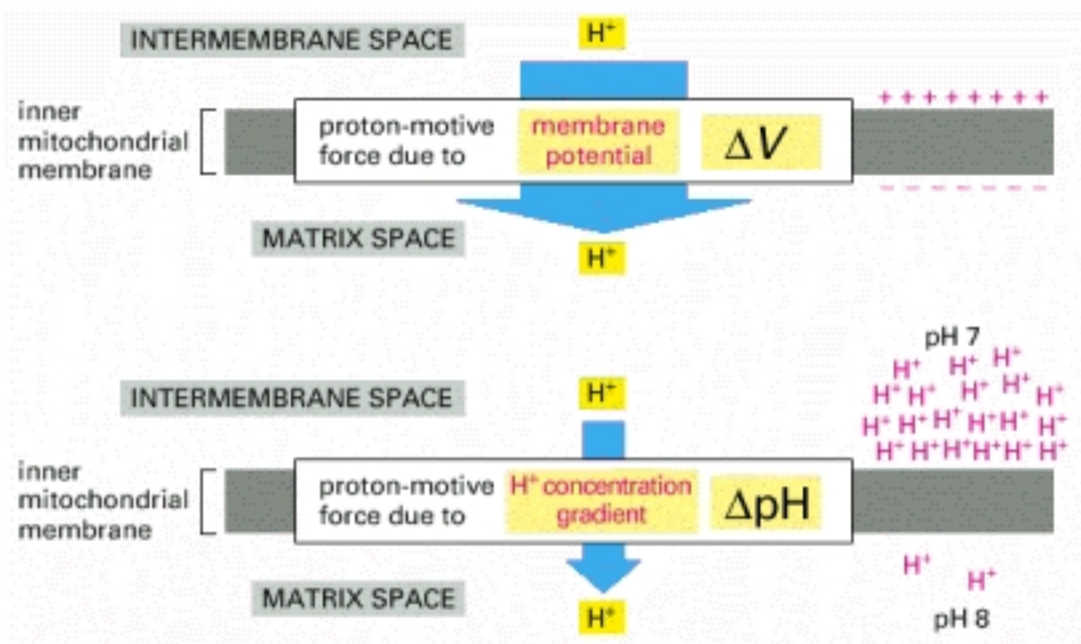

Figure 1: The components of an electrochemical proton gradient. The two components of the electrochemical proton gradient consist of a proton-motive force and H+ concentration gradient which both act to drive H+ into the matrix (*Figure from* Alberts *et al,* 2002).

Hydroelectricity is electrical energy generated from the power of water known as hydropower. This is done by employing the gravitational force of falling water where the motion of running water (kinetic energy) is converted into electricity (Maehlum, 2013). By letting the water flow through turbines on their way to the sea, we can harness some of the potential energy of elevated water to produce electricity much like the creation of ATP through the process of ATP synthase. The key elements for hydropower are "head" and "flow." The height of the gradient over which the water falls is the "head," and the volume of water per unit time is the "flow" (Carrasco *et al,* 2012). To maximize energy production, both head and flow should be high because the flow and head determines the potential energy of a waterfall. Since water releases gravitational potential energy as it flows downwards, rivers and streams have a downhill gradient similar to the proton gradient which relies on electrochemical gradient. With the help of a hydroelectric dam, this gravitational potential energy can be converted into kinetic energy within a turbine. Gates on the dam open and gravity pulls the water through the penstock, a pipeline that leads to the turbine. Water builds up pressure as it flows through the pipe where it strikes and turns the blades of a turbine. The turbine has a long shaft connected to it, which in turn is connected to a generator. As the shaft begins to turn due to the force of the turbine turning, it results in the creation of rotational energy in the shaft, which ultimately drives the generator and results in the generation of electricity as seen in Figure 2. This electricity is then sent to a transformer, which brings it to a usable voltage level before transmitting it across the national grid to people's homes (Jeske, n.d). Similarly, as protons go through the ATP synthase, it causes the rotation of the central shaft which converts electrochemical energy to mechanical energy in the form of ATP which is diffused out of the mitochondria and transported to different areas of cells needing energy.

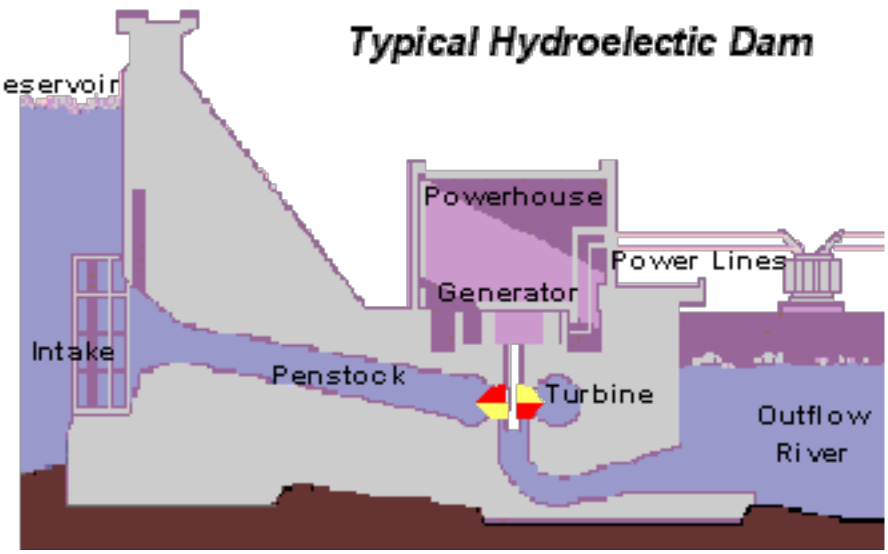

Figure 2: Different components of a hydropower plant. The reservoir stores water and the penstock is where the water flows down and turns on the turbine and the generator creates electricity. Hydropower plants generate electricity from the buildup gradient of water going down the penstock due to gravitational pull (*figure from* Perlman, n.d).

Why:

The electrochemical gradient of protons is essential to the creation of ATP which is a source of energy for cellular function. Due to the high concentration of H+ in the intermembrane, the protons "want" very strongly to move not only down their concentration gradient but also towards the opposite (negative) charge found on the other side of the membrane as seen in Figure 3. The potential energy associated with this can be trapped by the proteins that allow protons to move across the membrane, converting their potential energy to kinetic energy and then tapping that kinetic energy to do work (Gruber, n.d.). The proton gradient flowing down the membrane enzyme complex, ATP synthetase, is the direct energy source for producing ATP (Berg *et al,* 2002). ATP synthase cannot occur without a proton gradient. Without the active pumping of protons to one side of the membrane, the proton concentrations on both sides soon equalize. No longer do protons rush through the ATP-producing complex, and no more ATP is produced. Cells can't live long on the small quantity of ATP made by glycolysis, so without the ATP that comes from the electron transport chain, the cell dies (Electron Transport Chain, n.d). According to studies, the concentration gradient of protons in the electron transport chain can generate about 34 ATP per sugar molecule through ATP synthesis. Glycolysis can generate 4 ATP but have a net gain of 2 ATP. That is not enough for the function of cells. Since there is no proton concentration gradient, ATP molecules are consistently being made in glycolysis. Not only does the electron transport chain generate 34 ATP which is transported to other organelles, when the cell has excess energy, the energy is stored in the proton gradient. ATP synthase is put on hold (Albert *et al,* 2002).

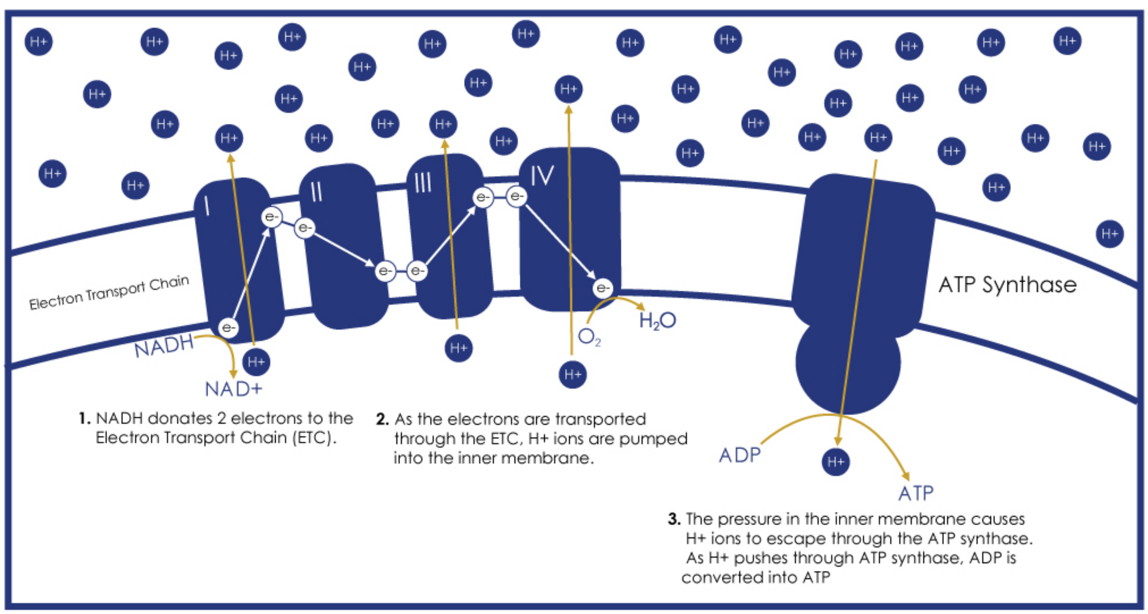

Figure 3: A simplify explanation of the process of the electron transport chain. The difference between the mitochondrial matrix and the intermembrane proton concentration creates a voltage difference. The difference causes the protons to move down their gradient through the enzyme ATP synthetase (*figure from* Winkler, n.d).

The amount of electricity created by the hydroelectric plant is directly proportional to river flow. The more that water falls through the turbine, the more power it will produce. The amount of water available depends on the amount of water flowing down the river. Bigger rivers have more flowing water and can produce more energy. A river with twice the amount of flowing water as another river can produce twice as much energy (Hydroelectric power, n.d). In 2011, hydropower provided 16% of the world's electricity, second only to fossil fuels because using hydro power liberates any sort of pollution and since water is a free source, the price to harness electricity would be far less (How Hydroelectric Energy Works, n.d). As seen in Figure 4, the Hoover Dam stores water which is used to generate electricity that is transported by the electrical wires. When electricity is not needed, the function of the dam is closed and the water is stored.

Figure 4: Hoover Dam, an image taken by an unknown. It is a gravity-arch dam designed for hydroelectricity (Saeta, 2011).

References

Alberts B, Johnson A, Lewis J, et al. (2002) Molecular Biology of the Cell. 4th edition. New York: Garland Science; The Mitochondrion.Available from: http://www.ncbi.nlm.nih.gov/books/NBK26894/

Berg JM, Tymoczko JL, Stryer L. (2002) Biochemistry. 5th edition. New York: W H Freeman; Section 18.4, A Proton Gradient Powers the Synthesis of ATP. Available from: http://www.ncbi.nlm.nih.gov/books/NBK22388/

Carrasco, J., & Pain, A. (2012). Hydropower (Large-scale). Retrieved April 28, 2016, from http://www.sswm.info/content/hydropower-large-scale

Chemiosmotic Gradient: Generation and Maintenance. (n.d.). Retrieved April 20, 2016, from http://www.ruf.rice.edu/~bioslabs/studies/mitochondria/mitogradient.html

Electron Transport Chain. (n.d.). Retrieved April 28, 2016, from http://www.sumanasinc.com/webcontent/animations/content/0402d_script.html

Gruber, J. (n.d.). The Electron Transport Chain. Retrieved April 28, 2016, from https://online.science.psu.edu/biol011_sandbox_7239/node/7357

How Hydroelectric Energy Works. (n.d.). Retrieved April 28, 2016, from http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/how-hydroelectric-energy.html#.VyDPXqMrKb8

Hydroelectric power - renewable energy. (n.d.). Retrieved April 28, 2016, from http://renewableenergy.ie/hydroelectric-power/

Jeske, J. (n.d.). Hydroelectricity. Retrieved April 28, 2016, from http://www2.hesston.edu/Physics/hydroelectricityjeske/research_paper.htm

Kent, G. (n.d.). Electron Transport Chain Animation. Retrieved April 20, 2016, from http://www.science.smith.edu/departments/Biology/Bio231/etc.html

Lane, N. (2010) Why Are Cells Powered by Proton Gradients? *Nature Education* 3(9):18. Available from: http://www.nature.com/scitable/topicpage/why-are-cells-powered-by-proton-gradients-14373960

Maehlum, M. (2013, May 3). How Does Hydroelectric Power Work? Energy Informative. Retrieved April 20, 2016, from http://energyinformative.org/how-does-hydroelectric-power-work/

Perlman, H. (n.d.). Hydroelectric power: How it works. Retrieved April 27, 2016, from http://water.usgs.gov/edu/hyhowworks.html

Saeta, P. (2011). Hoover Dam. Retrieved April 26, 2016, from http://www.physics.hmc.edu/~saeta/courses/p80/wiki/uploads/Main/HooverSpan.jpg

Winkler, J. (n.d.). How ATP is Synthesized in ETC. Retrieved April 27, 2016, from http://primonutra.com/wp-content/uploads/2016/03/How-ATP-is-Synthesized-in-the-ETC.jpg

Wilkin, D., & Gray-Wilson, N. (2014, December 5). The Electrochemical Gradient. Retrieved April 26, 2016, from http://www.ck12.org/biology/The-Electrochemical-Gradient/lesson/The-Electrochemical-Gradient-Advanced-BIO-ADV/