Efficiency of ATP Production

# Introduction

Endergonic reactions require energy input in order to proceed (see GIBB'S FREE ENERGY). Almost every time a cell performs an endergonic reaction, such as linking amino acids, synthesizing small molecules, or cellular movement, it derives the needed energy from the splitting of ATP. Aerobic organisms produce most of their ATP through respiration, a complex set of reactions that transfer electrons from glucose to oxygen. Glycolysis is the first step in glucose metabolism. The success of glycolysis lies in its ability to couple energy releasing reactions to the endergonic synthesis of ATP.

# Importance

# Because ATP is considered the universal currency of biological energy, it is important to learn how cells make ATP. Also, properties of cells and chemical reactions affect the efficiency of ATP production.

# Questions

# How can we determine the efficiency of ATP production?

# Variables

|  |  |
| --- | --- |
| N | number of ATP molecules formed |
| EATP | energy in one ATP bond |
| Ereact | energy released in chemical reaction |

# Methods

The predominant source of energy in animal cells is the sugar glucose. The reaction of glucose with oxygen under standard conditions can be described by the following chemical equation:

|  |  |
| --- | --- |
|  | LaTeX Code: \[ C\_6H\_{12}O\_6 + 6O\_2 \longrightarrow 6CO\_2 + 6H\_2O \] |

When 1 mol (180 g) of glucose reacts with oxygen under standard conditions, 686 kcal of energy is released (G0' = -686kcal/mol). If glucose is simply burned in air, all of this energy is released as heat. In the cell, however, this reaction is coupled to the synthesis of ATP from ADP in the following reaction:

|  |
| --- |
|  |
| LaTeX Code: \[ C\_6H\_{12}O\_6 + 6O\_2 + 36Phosphate + 36ADP \longrightarrow 6CO\_2 + 6H\_2O + 36ATP\] |

In other words, the energy released when glucose reacts with oxygen is coupled with an endergonic reaction in order to produce ATP. However, only a fraction of the released energy goes into the high-energy bonds of ATP. Since the overall reaction is exergonic, some energy is lost as heat.

We can determine the efficiency of ATP production by comparing the energy in ATP created by the reaction to the energy released by the reaction:

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| --- | --- |
|  | LaTeX Code: \[ efficiency = \frac{N \times E\_{ATP}}{E\_{react}} \times 100 \% \] |

where N is the number of ATP molecules formed and Ereact is the energy released as heat in the chemical reaction that is coupled with the reaction to form ATP. EATP is the energy in one high energy phophoanhydride bond in ATP, or the free energy when ATP reacts to form ADP and phosphate (ATP  ADP + phosphate).

Under standard conditions, Ereact = -686 kcal/mol and EATP = -7.3 kcal/mol. From the chemical reaction for the formation of ATP, we see that 36 molecules are formed. Therefore, we calculate the efficiency as

|  |  |
| --- | --- |
|  | LaTeX Code: \[ efficiency = \frac{36 \times 7.3}{686} \times 100 \% = 38.3 \% \] |

In other words, only about 38.3% of the energy released from the reaction of glucose with oxygen is captured in ATP bonds.

# Interpretation

An ATP efficiency of 38.3% is calculated under standard conditions (temperature is 298 Kelvin, pressure is 1 atm, pH is 7.0, and initial concentrations of reactants and products are equal). An EATP of -7.3 kcal/mol requires ATP, ADP, and phosphate to be present at equal concentrations.

In cells, however the concentration of ATP is often 5 to 10 times that of ADP. As a result, the free energy of ATP hydrolysis is about -12 kcal/mol. In cells, the efficiency of energy extraction from glucose is approximately 50%. As a comparison, the efficiency of an electric motor or gasoline engine is about 10% to 20%.

# Conclusion

By examining the chemical reaction of glycolysis, we can determine the efficiency of ATP production in cells. Properties of cells, particularly the high ratio of ATP to ADP, contribute to the efficiency of ATP production under cellular conditions. Respiration is a successful process because the capture of energy into ATP bonds is relatively efficient.

# Additional Questions

1. Look at the equation from GIBB'S FREE ENERGY for calculating G when the ratio of reactants to products does not equal 1:

|  |  |
| --- | --- |
|  | LaTeX Code: \[ \Delta G = \Delta G^{\circ \prime} + R \times T \times \ln \frac{C\_{product}}{C\_{reactant}} \] |

where T is temperature in Kelvin, R is the universal gas constant (1.987 cal/molK), and C gives the concentration of products and reactants, respectively.

The free energy from the hydrolysis of ATP (ATP  ADP + phosphate), under standard conditions, is G0' = -7.3 kcal/mol. Assume the temperature in a particular cell is 320 K, the concentration of ATP is 0.4mg/mL, the concentration of ADP is 0.04 mg/mL, and the concentration of phosphate is 0.02 mg/mL. Calculate the new G for ATP hydrolysis in this cell.

2. For the cell in question 1, what would the efficiency of ATP production be (assuming the free energy of the glucose reaction is still -686 kcal/mol)?

3. Oxidative phosphorylation is a step-in respiration that allows for the synthesis of approximately 2.5 moles of ATP. The free energy for oxidative phosphorylation has a G = -53 kcal/mol. What is the efficiency of ATP production from oxidative phosphorylation (assume cellular EATP = -12 kcal/mol)?

# Source

Darnell, J., H. Lodish, and D. Baltimore. 1986. *Molecular Cell Biology*. Scientific American Books, Inc., New York

Tobin, A. J. and R. E. Morel. 1997. *Asking About Cells*. Harcourt Brace & Company, New York.

# About this Resource

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This material is now being revised as part of the “Resources for Improving Quantitative Skills in Community College Biology[[2]](#endnote-2)” project. As part of that project is also aligned with the OpenStax Biology Textbook[[3]](#endnote-3).

It is published using the QUBES Open Education Resources publishing platform[[4]](#endnote-4).

1. http://www.tiem.utk.edu/~gross/bioed/ [↑](#endnote-ref-1)
2. https://qubeshub.org/community/groups/quantbioatcc/ [↑](#endnote-ref-2)
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