

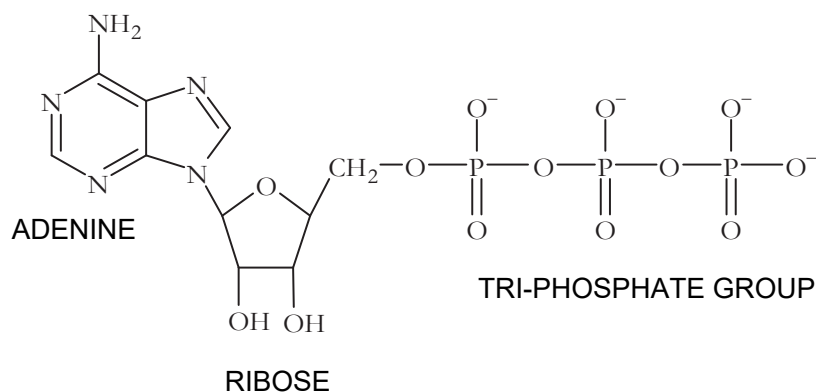
# ATP—The Free Energy Carrier

How does the ATP molecule capture, store, and release energy?

## Why?

A sporting goods store might accept a \$100 bill for the purchase of a bicycle, but the corner store will not take a \$100 bill when you buy a package of gum. That is why people often carry smaller denominations in their wallets—it makes everyday transactions easier. The same concept is true for the energy transactions in cells. Cells need energy (their “currency”) to take care of everyday functions, and they need it in many denominations. As humans we eat food for energy, but food molecules provide too much energy for our cells to use all at once. For quick cellular transactions, your cells store energy in the small molecule of ATP. This is analogous to a \$1 bill for your cells’ daily activities.

## Model 1 – Adenosine Triphosphate (ATP)



1. The diagram of ATP in Model 1 has three parts. Use your knowledge of biomolecules to label the molecule with an “adenine” section, a “ribose sugar” section, and a “phosphate groups” section.
2. Refer to Model 1.
  - a. What is meant by the “tri-” in the name adenosine triphosphate?

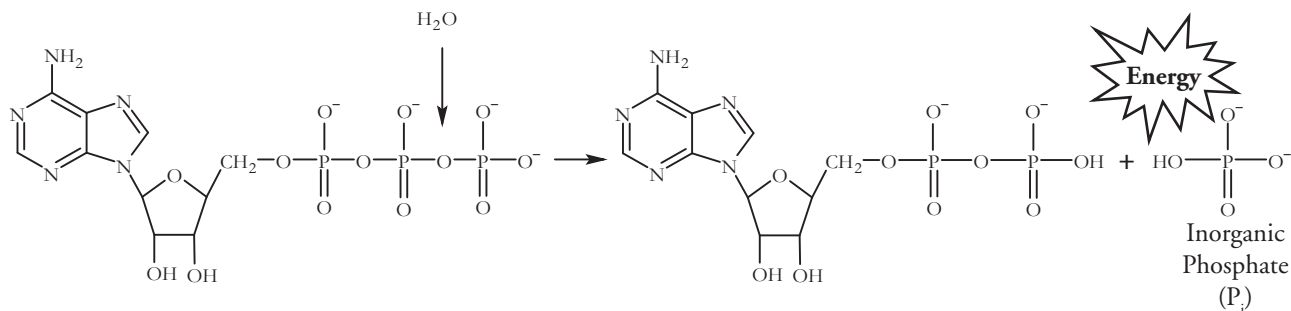
3 PHOSPHATES

- b. Discuss with your group what the structure of adenosine diphosphate (ADP) might look like. Draw or describe your conclusions.

SAME AS ABOVE, BUT WITH ONLY 2 PHOSPHATES IN PHOSPHATE GROUP.



## Model 2 – Hydrolysis of ATP



3. Model 2 illustrates a chemical reaction. Write the reaction as an equation, using the name or abbreviation of each of the two reactants and each of the three products.



4. Consider the structural formulas of ATP, ADP, and phosphate in Model 2 carefully. What happens to the atoms from the water molecule during the hydrolysis of ATP?

WATER IS INCORPORATED IN THE ADP MOLECULE AND IN THE FORMATION OF INORGANIC PHOSPHATE

5. The word **hydrolysis** has two roots, *hydro* and *lysis*. Describe how this term relates to the chemical reaction illustrated in Model 2.

HYDROLYSIS: SPLITTING OF A MOLECULE BY WATER

6. Refer to Model 2.

- a. Does the hydrolysis of ATP result in a net output, or a net input of energy?

A NET OUTPUT. ENERGY IS RELEASED WHEN A PHOSPHATE BOND IS BROKEN

- b. Which molecule, ATP or ADP, has a higher potential energy? Explain your reasoning.

ATP. IT CONTAINS STORED ENERGY IN PHOSPHATE BONDS

7. Consider Model 2.

- a. Is the process endothermic or exothermic?

**EXOTHERMIC**

- b. Recall that all bonds require energy to break, but energy is released when bonds are formed. With this in mind, explain why it is incorrect to say that the phosphoester bond in ATP releases a large amount of energy when ATP turns into ADP.

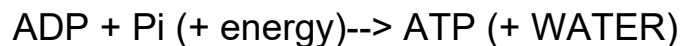
**THE ENERGY RELEASED IN THE BREAKING OF THE PHOSPHATE BONDS COME FROM WHEN THE WATER MOLECULES ARE ADDED TO THE ENDS OF THE ADP AND PHOSPHATE PIECES, NOT FROM THE ACTUAL "BREAKING" OF PHOSPHATE BONDS.**

## Read This!

The conversion of ATP to ADP is not only exothermic, but there is also an increase in entropy of the system. Therefore, the hydrolysis of ATP is exergonic, and provides free energy for many processes needed to sustain life.

8. The reaction in Model 2 is reversible.

- a. Write a reaction for the process that is the reverse of Model 1.



- b. This reaction is called **phosphorylation**. Explain why this name is appropriate for the reaction above.

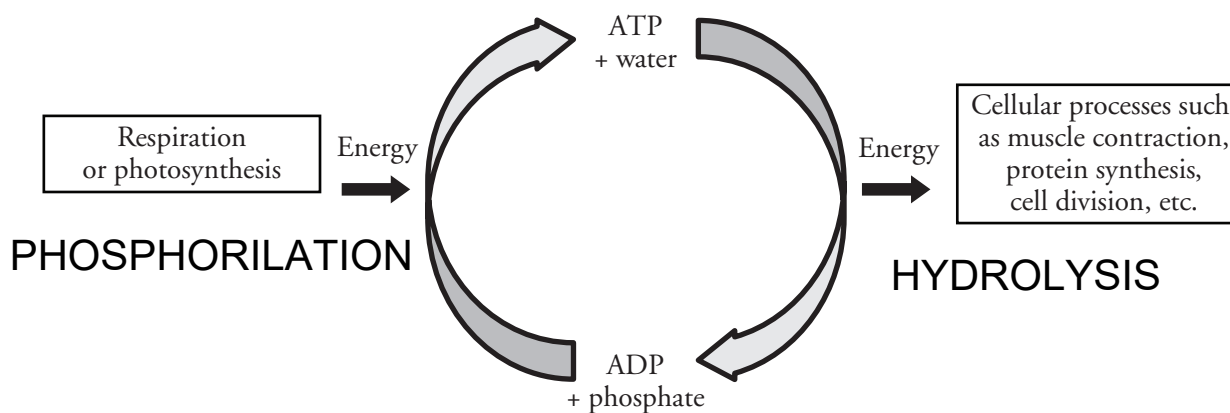
**BECAUSE A PHOSPHATE GROUP IS ADDED TO THE ADP MOLECULE**

- c. Would you expect this reaction to be endergonic or exergonic? Explain your reasoning.

**THE REACTION IS ENDERGONIC. THE ENERGY RELEASED FROM ATP INTO ADP NEEDS TO BE REPLACED.**



## Model 3 – The ATP Cycle



9. Label the two large arrows in Model 3 with “hydrolysis” and “phosphorylation.”



10. When ATP is hydrolyzed, free energy is available.

a. According to Model 3, what does that energy get used for?

**FOR WORK IN THE CELL SUCH AS ACTIVE TRANSPORT, MUSCLE CONTRACTION, AND CELL DIVISION**

b. Name at least two other cellular processes that could be fueled by the hydrolysis of ATP that are not listed in Model 3.

**MOVEMENT OF THE CELL, PROTEIN SYNTHESIS, DNA REPLICATION, ETC..**



11. After it is used, an ADP molecule is recycled back into ATP. What cellular, exergonic processes supply the energy needed for the phosphorylation of ADP?

**CELLULAR RESPIRATION WILL PRODUCE MORE ATP THAT WILL HELP AN ENZYME (ATP SYNTHASE) PHOSPHORILATE ADP INTO ATP**

12. In the *Why?* box at the start of this activity, an analogy was made between money and cellular energy.

a. What part(s) of the ATP cycle are analogous to earning money?

**WHEN ADP IS PHOSPHORILATED INTO ATP**

b. What part(s) of the ATP cycle are analogous to spending money?

**WHEN ATP IS HYDROLYZED INTO ADP + ENERGY**

c. What would be analogous to saving money in the context of ATP?

**ATP STORED IN THE CELL**



## Extension Questions

13. Describe or draw a diagram of adenosine monophosphate (AMP).

LOOKS LIKE AN ATP MOLECULE (MODEL 1) BUT ONLY HAS ONE PHOSPHATE GROUP ATTACHED TO RIBOSE.

14. If ADP were to be hydrolyzed in a similar manner to ATP, would you expect the reaction to be endergonic or exergonic? Explain your answer.

EXERGONIC. WATER MOLECULES ARE BEING ADDED TO EACH OF THE RIBOSE AND PHOSPHATE PIECES OF THE MOLECULE TO MAKE AMP AND P<sub>i</sub>. AND ENERGY IS BEING RELEASED FROM THIS BOND-FORMING REACTION.

## Read This!

It is estimated that more than  $2 \times 10^{26}$  molecules of ATP are hydrolyzed in the human body daily. If each molecule was used only once you would need approximately 160 kg (350 lbs) of ATP daily. The repeated use of ATP molecules through the ATP cycle saves the body a huge amount of resources and energy.

ATP is synthesized in two ways:

- **Substrate-level phosphorylation**—Energy released during a reaction, such as the breakdown of sugar molecules, is used directly to synthesize ATP. A small amount of energy is generated through this process.
- **Electron transfer (oxidative phosphorylation)**—Energy from the movement of electrons from one molecule to another, via electron carriers, is used to synthesize ATP. Most cellular ATP is synthesized by electron transfer in the mitochondria.

15. Dinitrophenol (DNP) is an “uncoupler,” which means it interferes with the flow of electrons during electron transfer. Fifty years ago, DNP was given as a drug to help patients lose weight.
- a. Why would taking DNP make someone lose weight?

DNP MAKES IT IMPOSSIBLE FOR THE BODY TO SYNTHESIZE ENOUGH ATP BY OXIDATIVE PHOSPHORILATION. THE BODY'S ONLY SOURCE OF ATP WOULD BE FROM SUBSTRATE-LEVEL PHOSPHORILATION VIA THE BREAKDOWN OF GLUCOSE. THIS MEANS ALL ATP WOULD COME FROM FOOD (GLUCOSE), GLUCOSE WOULD NOT BE STORED, AND NO ONE WOULD STORE FAT.

- b. Why would taking DNP be dangerous?

BECAUSE ENERGY (ATP) FROM SUBSTRATE-PHOSPHORILATION (GLUCOSE) ALONE IS NOT ENOUGH TO SUSTAIN LIFE PROCESSES.