Biol 12000 Biology 1B Life Processes – Animal Physiology

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Lectures

19: Introduction to bioenergetics
20: Glycolysis
21: Krebs cycle & electron transport chain
22: Respiration in water
23: Respiration in air
24: Blood and circulation
25: Control of respiration
26: Chemical communication
27: Endocrine control

One of the key terms, respiration ("to breathe") has different meanings in biochemistry and physiology, both of which will be included here:

Biochemistry - "the oxidation of organic fuels to supply energy in the cell" - cellular respiration

Physiology - "the process of uptake of oxygen and release of carbon dioxide by an organism" - organismal respiration

Usually both are just referred to as "respiration", need to take context into account to decide which is meant

Practicals

1: Oxygen consumption in goldfish, OR

Nitrogen excretion in crayfish AND optical absorbance of haemoglobin

Due Friday 6 December

2: Nitrogen excretion in crayfish AND optical absorbance of haemoglobin, OR

Oxygen consumption in goldfish

Due Friday 6 December

3: Endocrine control of colour change in tadpoles

Due Wednesday 11 December

Life 19 - Introduction to bioenergetics – Raven & Johnson Chapters 8 & 9 (parts)

Objectives

1: Understand the importance of energy in biological systems

2: Understand the first and second laws of thermodynamics and their relevance to biology

3: Explain the energy requirements of endergonic and exergonic reactions

4: Describe how oxidation and reduction are interrelated in chemical reactions, as the transfer of electrons

5: Explain the action of NAD^+ as an electron acceptor in the cell

6: Understand the structure of ATP and how it functions as an energy carrier

Introduction to bioenergetics

The properties of life (maintaining order, growth, movement, etc) all require a constant supply of energy

Autotrophs (producers, "self-feeders") - use inorganic compounds only to make their organic requirements, usually by photosynthesis. Light energy captured as high-energy electrons in chemical bonds

Heterotrophs (consumers, "fed by others") need organic molecules for energy and building blocks for synthesis. All animals & fungi, most protists & bacteria, many plant cells

Energy transformation in cells is the subject of bioenergetics; all cells use the same fundamental molecular principles & mechanisms

Many forms of energy, can all be converted into heat. Calorie = 1 g of water increased by 1 C. The SI unit is the Joule, for all types of energy. 1 cal = 4.18 J

Study of energy is also known as thermodynamics ("heat changes"). Laws govern all energy changes

No vitalism in living organisms - they obey the laws of thermodynamics

First Law: Energy is conserved, can only change form. In any energy transformation, some is lost as heat (random molecular motion)

Second Law: Deals with directionality of change. The disorder or entropy of the universe is continually increasing. Other energy eventually dissipated as heat

Combining these gives the Gibbs free energy (G), that available to do work, at constant pressure and temperature. Change in free energy during a reaction

$$\Delta G = \Delta H - T\Delta S$$

ΔH is change in enthalpy (total energy in bonds and heat)
ΔS is change in entropy (disorder), T is absolute temperature (Kelvin)
$T\Delta S$ is energy unavailable because of disorder

ΔG is positive in reactions which need an energy input, as the bond energy (H) increases or the disorder (S) decreases. Endergonic reactions ("inward energy"); uphill for energy (Fig. 8.6)

ΔG is negative in reactions which liberate energy. Exergonic ("outward energy") reactions, tend to proceed spontaneously (but not necessarily instantaneously); downhill

ΔG expressed in kilojoules (1000 J) per mole of reactants: kJ $mole^{-1}$

Even exergonic reactions may need to overcome an activation energy, to break existing bonds first

Enzymes are catalysts because they lower this activation energy, make the reaction more likely to proceed (Fig. 8.7)

Energy is stored in covalent bonds of organic molecules, as electrons in shared orbits

In a reaction, energy may be transferred to new bonds, as an electron (e^-) is passed between atoms or molecules

A molecule losing an electron is oxidised, in the process of oxidation. It loses the electron to an electron acceptor. Oxygen is the most common final electron acceptor (Fig. 8.4)

A molecule gaining an electron is reduced, in the process of reduction. It gains an electron from an electron donor. Biological fuels are electron donors

Oxidation and reduction occur together, in redox reactions

Energy is transferred with the electron, usually with a proton (= hydrogen ion H^+) as a hydrogen atom. The reduced molecule gains energy, the oxidised molecule loses energy

All bioenergetics processes are redox reactions, even without oxygen, for example in fermentation. Energy is transferred between molecules with transfer of electrons

Nicotinamide adenine dinucleotide (NAD^+) is a biological electron acceptor, giving the reduced form NADH (Fig. 9.15)

NAD^+ reacts with 2 hydrogen atoms. NADH carries the two energetic electrons plus one proton

$$NAD^+ + 2H\ (2e^- + 2H^+) \Rightarrow NADH + H^+$$

Oxidation of energy-rich organic molecules occurs by stripping electrons (as H) and donating these to NAD^+

Energy is conserved in the energy-carrier molecule adenosine triphosphate (ATP). Carries energy between oxidation and energy-consuming processes such as synthesis, active transport

ATP is a nucleotide made up of Ribose, Adenine, and a chain of three phosphates (triphosphate) (Fig. 9.3)

Phosphates are ionised at pH 7 in the cell. Electrostatic repulsion destabilises the 2 covalent bonds joining them; "a coiled spring"

Much energy is liberated when they break. Usually the outer phosphate is lost to form adenosine diphosphate (ADP), with $\Delta G = -30.5 \text{ kJ mole}^{-1}$

Use of ATP. An enzyme has 2 binding sites, one for the reactant and one for ATP. The ATP site splits ATP, liberating energy. The enzyme enters an active state, drives reaction (Fig. 9.4)

Or the high-energy phosphate may be transferred to the reactant, where the 2 sites are close together on the enzyme

If splitting ATP liberates more energy than the other reaction consumes, the overall reaction is exergonic and they will both proceed. For example:

Glutamic acid + $NH_3 \Rightarrow$ glutamine $\Delta G = + 14.2 \text{ kJ mole}^{-1}$

Combined with splitting ATP, the overall reaction is:

ATP + glutamic acid + $NH_3 \Rightarrow$ glutamine + ADP + Pi ($\Delta G = -16.3 \text{ kJ mole}^{-1}$, i.e.14.2-30.5), where Pi is inorganic phosphate. The combined reaction is exergonic and will proceed

Change in free energy is between the reactants and the products. It does not matter which route the reaction takes

In this case the route is through glutamyl phosphate, catalysed by the enzyme glutamine synthetase (a high-energy phosphate is shown as ~P)

ATP + glutamic acid $\Rightarrow$ glutamyl phosphate + ADP (takes ~P from ATP)

Glutamyl phosphate + $NH_3 \Rightarrow$ glutamine + Pi (decays, replacing ~P with NH_3)

Phosphate bonds are unstable, not good for long-term storage. Cells contain small quantities of ATP (a few seconds supply), continually being replenished from ADP and Pi, and energy from biological fuels

Carbohydrates, proteins and fats from food or storage are all rich in energy-laden chemical bonds, especially C-H. Enzymes break large food molecules into smaller pieces in digestion (read Chapter 51)

Other enzymes then dismantle the pieces in stages, harvesting energy from bonds to produce ATP. This is catabolism, e.g. of glucose, a carbohydrate

Chemically, catabolism of carbohydrates is equivalent to burning wood:

$$C_6H_{12}O_6 + 6O_2 \Rightarrow 6\ CO_2 + 6\ H_2O + \text{energy}$$

$\Delta G = -3010$ kJ mole^{-1} glucose, mostly from the 6 C-H bonds; equivalent to about 100 ATP

The same energy is liberated in catabolism as in burning; ΔG is irrespective of the route. Burning loses all this energy as heat, but catabolism saves some of it as ATP

Cells make ATP by several stages, examined in lectures 20 & 21