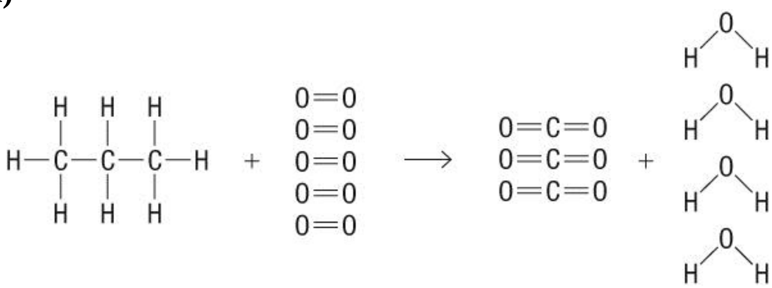
Section 3.1: Metabolism and Energy

Tutorial 1 Practice, page 133

1. (i) $C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$

(ii)



Reactants

Bond	Average bond energy (kJ/mol)	Number of bonds in propane	Number of bonds in oxygen	Total bond energy
C–H	411	8		3288
O–H	459			
C–C	346	2		
C–O	359			
C=O	799			
O=O	494		5	2470

total bond energy = 3288 kJ + 2470 kJ
= 6458 kJ

Products

Bond	Average bond energy (kJ/mol)	Number of bonds in water	Number of bonds in carbon dioxide	Total bond energy
C–H	411			
O–H	459	8		3672
C–C	346			
C–O	359			
C=O	799		6	4794
O=O	494			

total bond energy = 3672 kJ/mol + 4794 kJ/mol
= 8466 kJ/mol

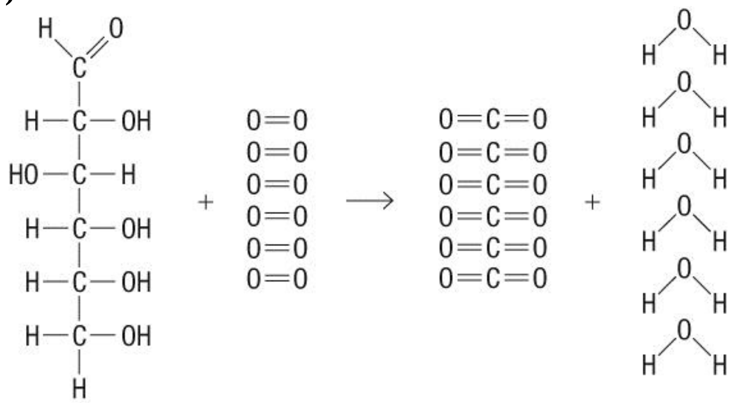
(iii) net energy change = total bond energy of products − total bond energy of reactants
= 8466 kJ/mol − 6458 kJ/mol
= 2008 kJ/mol

(iv) molar mass of propane, C_3H_8 = 44 g/mol

(v) energy = (number of mol)(energy per mol)
= (1/44 g/mol)(2008 kJ/mol)
= 45.64 kJ/g

(vi) Therefore the amount of energy released from the combustion of propane with oxygen is 46 kJ/g.

2. (i) $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$
(ii)



Reactants

Bond	Average bond energy (kJ/mol)	Number of bonds in propane	Number of bonds in oxygen	Total bond energy
C–H	411	7		2877
O–H	459	5		2295
C–C	346	5		1730
C–O	359	5		1795
C=O	799	1		799
O=O	494		6	2964

total bond energy = 9496 kJ + 2964 kJ
= 12 460 kJ

Products

Bond	Average bond energy (kJ/mol)	Number of bonds in water	Number of bonds in carbon dioxide	Total bond energy
C–H	411			
O–H	459	12		5508
C–C	346			
C–O	359			
C=O	799		12	9588
O=O	494			

total bond energy = 5508 kJ/mol + 9588 kJ/mol
= 15 096 kJ/mol

(iii) net energy change = total bond energy of products − total bond energy of reactants
= 15 096 kJ/mol − 12 460 kJ/mol
= 2636 kJ/mol

(iv) molar mass of glucose, $C_6H_{12}O_6$ = 44 g/mol

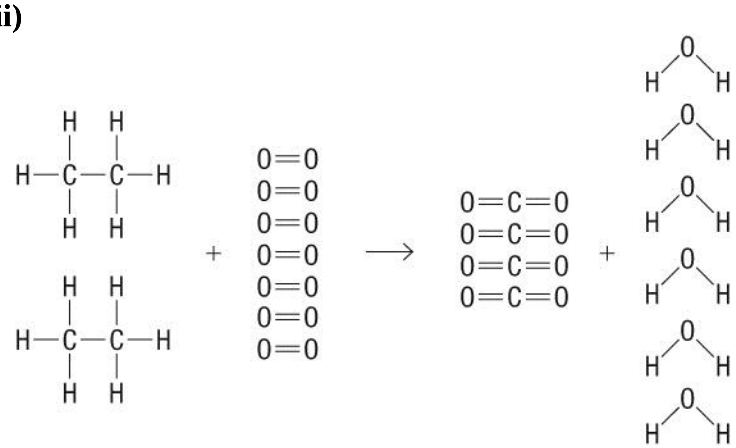
(v) energy = (number of mol)(energy per mol)
= (1/180 g/mol)(2636 kJ/mol)
= 14.6 kJ/g

(vi) Therefore the amount of energy released from the combustion of glucose with oxygen is 15 kJ/g.

3. Methane has more potential energy than butanoic acid does (50 kJ/g vs 23 kJ/g). Methane contains many more carbon–hydrogen bonds per carbon than butanoic acid does. Because of this, when the molecular weight is corrected for, the ratio of higher-energy to lower-energy bonds per carbon results in more potential energy.

Section 13.1 Questions, page 140

1. (a) The relationship between energy and work is that energy is the ability to do work. Work is done when an object is moved by using energy.
(b) The relationship between potential energy and kinetic energy is that potential energy is energy associated with position or structure of an object and can be converted into kinetic energy—the energy associated with motion.
(c) The relationship between free energy and spontaneous changes is that free energy is energy available to do work and spontaneous changes result in a reduction of free energy in the system.
2. The relationship between bond energy and energy changes that occur during a chemical reaction is bond energy is the energy needed to break a bond or the energy released when a bond forms and energy changes that occur are a result of the comparison between the chemical potential energy of the products and the chemical potential energy of the reactants. During any chemical reaction some energy is absorbed when bonds in the reactants break and some energy is released when bonds form in the products. This change in bond energy is measured as the energy change of a reaction.
3. (a) (i) $2\ C_2H_6 + 7\ O_2 \rightarrow 4\ CO_2 + 6\ H_2O$
(ii)



(iii) Reactants

Bond	Average bond energy (kJ/mol)	Number of bonds in propane	Number of bonds in oxygen	Total bond energy
C–H	411	12		4932
O–H	459			
C–C	346	2		692
C–O	359			
C=O	799			
O=O	494		7	3458

total bond energy = 5 624 kJ + 3458 kJ
= 9 082 kJ

Products

Bond	Average bond energy (kJ/mol)	Number of bonds in water	Number of bonds in carbon dioxide	Total bond energy
C–H	411			
O–H	459	12		5508
C–C	346			
C–O	359			
C=O	799		8	6392
O=O	494			

total bond energy = 5508 kJ/mol + 6392 kJ/mol
= 11 900 kJ/mol

(iv) net energy change = total bond energy of products − total bond energy of reactants
= 11 900 kJ/mol − 9082 kJ/mol
= 2818 kJ/mol

(v) molar mass of ethane C_2H_6 = 30 g/mol

(vi) determine energy = (energy per mol)/ (number of mol)
= (2 818 kJ/mol)/ ((2) (30 g/mol))
= 47 kJ/g

vii) The amount of energy released from the combustion of ethane with oxygen is 47 kJ/g. This makes this reaction exothermic.

(b) There is much more energy per gram from ethane than from either glucose (15 kJ/g) or butanoic acid (23 kJ/g).

(c) Hydrocarbons have the highest energy content followed by fats and then carbohydrates. This is because hydrocarbons contain a higher ratio of high-energy C–H bonds per carbon than the other molecules do.

4. Given: $E_{products}$ = 1386 kJ/mol
$E_{reactants}$ = 1250 kJ/mol

Required: ΔE

Analysis: $\Delta E = E_{products} - E_{reactant}$

Solution: ΔE = 1386 kJ/mol −1250 kJ/mol
= 136 kJ/mol

Statement: Overall, there is a net release of 136 kJ/mol, so the reaction is exothermic.

5. In order to see that an organism can grow and create internal order without violating the second law of thermodynamics, you must take both the organism and its surroundings into account. The organism experiences a decrease in entropy, but it must have a continual supply of energy to do this. Also, the cell expels waste products and waste thermal energy to its surroundings such that the entropy of the total system increases.

6. When a firefly releases light energy, the overall process must be exergonic. The production of light requires a source of free energy and this energy must have been supplied by an exergonic chemical reaction. This process abides by the first law of thermodynamics because chemical energy is being converted into light energy but energy is not being created or destroyed. It abides by the second law of thermodynamics because in producing the light the firefly would also release a small amount of waste energy, that is, the conversion from chemical to light energy would not have been 100 % efficient.
7. The difference between anabolic and catabolic pathways is the change in free energy as a result of the reaction. An anabolic pathway is a process in which complex molecules are built from simpler ones, requiring free energy. A catabolic pathway is a process in which large complex molecules are broken down into simpler ones, releasing free energy.
8. (a) When organic food waste decomposes, this is a spontaneous reaction. It is a catabolic process and results in an increase in entropy. It would occur when bacteria or fungi release digestive enzymes onto the food waste that break large molecules into smaller molecules, releasing energy for the bacteria or fungi to use.
(b) When a bacterial cell propels itself using a flagellum, this is non-spontaneous. The bacterial cell requires a source of free energy to move its flagellum. The bacteria would obtain this free energy by coupling the reactions needed to move the flagellum to exergonic chemical reactions.
(c) When a honey bee converts sucrose into glucose and fructose, this is a spontaneous reaction because it is a catabolic/exergonic reaction in which entropy increases. Bees might do this by converting sucrose they obtained from plants into honey.
(d) When an electric eel creates an electric field, this would be a non-spontaneous process since the eel would need a source of free energy. The eel would convert chemical potential energy in its food to electrical energy generated by specialized cells in its body.
9. (a) The first law of thermodynamics: energy transforms from one form to another or transfers from one object to another, but it is neither created nor destroyed. The second law of thermodynamics: in every transfer and conversion of energy, there is less energy available to do work; the total entropy of a system and its surroundings always increases.
(b) Answers may vary. Sample answer: When living things grow they become more orderly not less orderly, so it appears as if their actions reduce entropy. However, while their bodies may become more ordered, they release waste particles and waste thermal energy that results in an overall increase in entropy.
10. (a) This can be spontaneous. Answers may vary. Sample answer: An example of a spontaneous exothermic process that increases entropy in a setting with a low temperature would be the combustion of wood in the winter.
(b) Exothermic process that decreases entropy in a setting with a high temperature are not generally spontaneous.
(c) This can be spontaneous. Answers may vary. Sample answer: An example of an endothermic reaction that results in an increase in entropy in a setting with a high temperature is evaporating water on a hot day. The water releases the trapped thermal energy as a result of a phase change, which decreases the entropy of the system.
(d) There are no endothermic processes that decrease entropy at low temperatures. These reactions are nonspontaneous.