Energy from Fats & Sugars

Earlier we discussed the nature of fats and mentioned that fats typically provide 9 Cal/g of food energy, while sugars provide about 4 Cal/g. So in order to store the energy in 10 lb of fat, your body would need to store 22.5 lb of carbohydrates or sugars; but it's more extreme than that. Because sugars carry about their own weight of associated water in the body, 67.5 lb (31 kg) of hydrated glycogen has the energy equivalent of 10 lb (5 kg) of fat!\[^1\]

The food energy in various food types is given approximately in the following table \[^2\], and you can find the fat content (as well as all other nutritional information) about nearly all foods in the United States Department of Agriculture's Bulletin #8 which has a searchable USDA Nutrient database. In the database, fats are list under "lipids"/"Fatty Acids" and then under "saturated" and "18:0", indicating the number of carbon atoms (18) in the fatty acid, and the number of double bonds (0) (see Example 1).

<table>
<thead>
<tr>
<th>Food component</th>
<th>Energy Density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kJ/g</td>
</tr>
<tr>
<td>Fat</td>
<td>37</td>
</tr>
<tr>
<td>Ethanol (drinking alcohol)</td>
<td>29</td>
</tr>
<tr>
<td>Proteins</td>
<td>17</td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>17</td>
</tr>
<tr>
<td>Sorbitol, sugar alcohol sweeteners</td>
<td>10</td>
</tr>
<tr>
<td>dietary Fiber</td>
<td>8</td>
</tr>
</tbody>
</table>
A 1-2 g sample of food is sealed in a heavy walled steel cylinder (about 4" in diameter and 7" high), shown in the center of the Figure, which is then filled with pure oxygen at 30-40 atmospheres pressure, and immersed in a few liters of water. The sample is ignited electrically, and the heat released is determined by measuring the temperature increase of water that surrounds the "bomb".

**Thermochemical equations**

\[
\text{C}_{18}\text{H}_{36}\text{O}_2 (s) + 24 \text{O}_2(g) \rightarrow 18 \text{CO}_2(g) + 18 \text{H}_2\text{O}(l) \quad (25^\circ\text{C}, 1 \text{ atm pressure})
\]

\[\Delta H_m = -11407 \text{ kJ}\]  \[\text{(1)}\]

Here the \(\Delta H_m\) (delta \( H \) subscript \( m \)) tells us whether heat energy is released or absorbed when the reaction occurs and also enables us to find the actual quantity of energy involved. By convention, if \(\Delta H_m\) is positive, heat is absorbed by the reaction; i.e., it is endothermic. More commonly, \(\Delta H_m\) is negative as in Eq. (1), indicating that heat energy is released rather than absorbed by the reaction, and that the reaction is exothermic. This convention as to whether \(\Delta H_m\) is positive or negative looks at the heat change in terms of the matter actually involved in the reaction rather than its surroundings. In the reaction in Eq. (1), the C, H, and O atoms have collectively lost energy and it is this loss which is indicated by a negative value of \(\Delta H_m\).

It is important to notice that \(\Delta H_m\) is the enthalpy for the **reaction as written**. The quantity of heat released or absorbed by a reaction is proportional to the amount of each substance consumed or produced by the reaction. Thus Eq. (1) tells us that 890.4 kJ of heat energy is given off for **every mole of** \(\text{C}_{18}\text{H}_{36}\text{O}_2\) which is consumed. Alternatively, it tells us that 11407 kJ is released for **every 18 mole of** \(\text{H}_2\text{O}\) produced, or for **every 18 mol of** carbon dioxide produced, or **24 mol of** oxygen consumed. Seen in this way, \(\Delta H_m\) is a conversion factor enabling us to calculate the heat absorbed when a given amount of substance is consumed or produced. If \(q\) is the quantity of heat absorbed and \(n\) is the amount of
EXAMPLE 1

In the molecular model, each bend in the structure is occupied by a carbon atom, and each carbon atom has 4 bonds; missing bonds are to hydrogen atoms, which are not shown.

a. How much heat energy is obtained when 1 g of C_{18}H_{36}O_{2}, is burned in oxygen according to the equation above? The molar mass of steric acid is 284.48 g/mol.

b. What is the caloric value of 1 g of stearic acid, given that ΔH_m = –11407 kJ for equation (1)?

Solution

a. The mass of C_{18}H_{36}O_{2} is easily converted to the amount of C_{18}H_{36}O_{2} from which the heat energy q is easily calculated by means of Eq. (2). The value of ΔH_m is –11407 kJ per mole of C_{18}H_{36}O_{2}. The road map is

b.

Note: By convention a negative value of q corresponds to a release of heat energy by the matter involved in the reaction.

This is close to the estimated 9 Cal/g for fats. We saw earlier that most fats are triglycerides, that is, they would have 3 fatty acid substituents (like stearic acid) attached to a glycerol "backbone" in a fat like glycercyl tristearate ("stearin") (C_{57}H_{110}O_{6}, M = 891.48). Stearin has a heat of combustion of -35 663 kJ/mol, so 1 g produces (35 663 kJ/mol) / (891.48 g/mol) x (1 Cal / 4.184 kJ) = 9.57 Cal. When energy is required by our body, triglycerides are converted free fatty acids, and transported by serum albumin in the blood to cells where energy is required. Serum albumin is necessary because the solubility of fatty acids is low in water-based blood.

In comparison, sucrose (C_{12}H_{22}O_{11}) has a molar mass of 342.3 g/mol and a heat of combustion of -5645 kJ/mol, so it produces 16.49 kJ/g or 3.94 Cal/g, very close to the estimated value, by the combustion:

C_{12}H_{22}O_{11} (s) + 12 O_2(g) → 12 CO_2(g) + 11 H_2O(l) (25°C, 1 atm pressure)

ΔH_m = –5 645 kJ mol^{-1}[5]

Enthalpy change for the reaction as written

It is important to realize that the value of ΔH_m given in thermochemical equations like (1) depends on the physical state of both the reactants and the products. Thus, if water were obtained as a liquid instead of a gas in the reaction in Eq. (1), the value of ΔH_m would be different from -890.4 kJ. It is also necessary to specify both the temperature and pressure since the value of ΔH_m depends very slightly on these variables. If these are not specified [as in Eq. (3)] they usually refer to 25°C and to normal atmospheric pressure.

Two more characteristics of thermochemical equations arise from the law of conservation of energy. The first is that
writing an equation in the reverse direction changes the sign of the enthalpy change. For example,

\[ 2l_2gH_m \rightarrow 2g_2lH_mB_mB_mH_mH_mB_mH_mB_mH_mB_m \]

References

3. ↑ home.fuse.net/clymer/rq/hoctable.html
4. ↑ en.Wikipedia.org/wiki/Fatty_acid_metabolism
5. ↑ home.fuse.net/clymer/rq/hoctable.html

Contributors

- Ed Vitz (Kutztown University), John W. Moore (UW-Madison), Justin Shorb (Hope College), Xavier Prat-Resina (University of Minnesota Rochester), Tim Wendorff, and Adam Hahn.