ENERGY METABOLISM
HWA: Chapter 7

1. Animals obey the laws of thermodynamics
   A. Entropy (2nd Law of Thermodynamics)
2. Animals consume energy containing materials because energy is lost when moved through systems.

Figure 7.2 The uses of energy by an animal

Mechanical energy
Growth
Chemical energy
Accumulated in body tissues
Absorbed chemical energy
Growth
Absorbed chemical energy
Growth
Maintenance
Degradation of internal work
Degradation of internal work
Degradation of internal work
Degradation of internal work
Absorbed chemical energy is used to perform three major types of physiological work inside the body.

Figure 7.2 The uses of energy by an animal

Absorbed chemical energy...and leaves as heat, chemical energy, or external work.

Metabolic Rate

1. MR = energy metabolism per unit time
2. Can be calculated in several ways
   A. Method 1: Direct Calorimetry (heat production)
   B. Method 2: Indirect Calorimetry (Box 7.4)
      a. oxygen consumption in ml O₂/hr
   C. Method 3: Measure CO₂ production
      a. less useful measure of metabolic rate

Measuring heat production

1. Latent Heat of Fusion
   A. 80 calories to melt 1 g of ice
2. Or in Joules (SI unit) = kg m² sec⁻¹
   A. 1 cal = 4.186 J
   B. 80 cal/gram = 334 J/gram
   \[ C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 2820 \text{kJ/mol} \]

Lavoisier's experiment

1. In 10 hrs, 370 g of ice melted.
2. Latent heat of fusion for ice = 334 J/gram ice at 0°C
3. 334 J/g x 370 g = _______ J/10 hrs
4. or _______ J/hr

Table 7.1: Different foods contain different amounts of energy

<table>
<thead>
<tr>
<th>Foodstuff</th>
<th>Heat produced per unit O₂ consumed (J/ml, O₂)</th>
<th>Heat produced per unit CO₂ produced (J/ml, CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrates</td>
<td>21.1</td>
<td>21.1</td>
</tr>
<tr>
<td>Liquids</td>
<td>19.8</td>
<td>27.9</td>
</tr>
<tr>
<td>Proteins</td>
<td>18.7</td>
<td>23.3</td>
</tr>
</tbody>
</table>

3. RQ = Respiratory exchange ratio
   A. Ratio of CO₂ formed to O₂ used
   B. 1 for carbohydrates
   C. about 0.75 for fats and proteins
   D. a method of telling what food is being metabolized
Factors Affecting Metabolic Rate (Table 7.3)

1. Physical Activity
2. Environmental Temperature
3. Digestive Processing
4. Body Mass
5. Age
6. Gender
7. Endocrine Activity
8. Circadian Rhythms
9. Salinity

Terms

1. Basal Metabolic Rate (BMR)
   A. endotherms
2. Standard metabolic rate (SMR)
   A. Ectotherms
   B. Temperature dependent (Fig. 10.10)
3. Activity Metabolic rates
4. Metabolic Scope

Metabolic Rate (MR) and Body Size in Mammals

1. MR can be measured as specific oxygen consumption per unit of body mass or versus total body mass
2. Larger mammals have larger total metabolic rates
   A. but
3. Larger animals have lower mass-specific rates
   A.

Figure 7.6  The effect of body size on weekly food requirements in a mammal

Figure 7.7  BMR as a function of body weight in various species of placental mammals

Calculating Basal or Standard Metabolic Rate

\[ MR = aM^b \]

\[ \log MR = \log a + \log b \]

MR = Basal or standard metabolic rate
M = body mass
a = intercept of the log-log regression line
b = rate of change of log MR with change in log body mass
The relationship is linear on log axes

Figure 7.8 Weight-specific BMR as a function of body weight in various species of placental mammals

For Mammals
1. $V_{O2} = 0.676 \times M_b^{0.75}$
2. $V_{O2}/M_b = 0.676 \times M_b^{0.75} \times M_b^{-1.0}$
3. $V_{O2}/kg = 0.676 \times M_b^{-0.25}$

See Review Questions
1. Fill in the "?" values in the table using the allometric values given,
2. If $M=1$, then $MR = 10 \text{ ml O}_2 / \text{hr} = a^1 \times t$, $10 = a^1 \times t$
3. Calculate the times for a 100 g animal of each taxon to use 10 ml O2.
4. If $M=100$, then $MR = 10 \text{ ml O}_2 = a^{100} \times t$
Importance of scaling – e.g., Tusko’s bad trip

see web page for more information

1. an elephant weighs 1000 times as much as a cat,
2. Tusko received 1000 times more LSD than a cat.
3. The known cat dose is 0.1 mg LSD/kg.
   A. 0.26 mg LSD / 2.6 kg cat = 0.1 mg LSD / kg
4. Calculate dose for 2970 kg elephant

http://www.harding.edu/plummer/animphys/scaling.HTM

1. Recalculate dose for elephant based on known human dosage (by mass):
   A. 0.20 mg LSD / 70 kg human = 0.003 mg LSD/kg;
2. Calculate elephant dose based on cat or human metabolic rate

<table>
<thead>
<tr>
<th>Animal</th>
<th>Mass (kg)</th>
<th>MR/mass (O2/kg/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat</td>
<td>2.6</td>
<td>0.53</td>
</tr>
<tr>
<td>Human</td>
<td>70</td>
<td>0.23</td>
</tr>
<tr>
<td>Elephant</td>
<td>2970</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Another question from Animal Physiology -- Biology 462, University of Washington. Metabolism II -- Body Size, Endothermy vs. Ectothermy, Raymond B.Huey

1. Researchers had found that 500 mg/day acrylamide induces cancer in rats.
2. See Review Questions for more information and answers to the following.
   1. What is the equivalent dose for humans if it scales directly with mass (1 kg rat; 70 kg human)
   2. Compute the daily safe dose if risk scales not with mass but with total metabolic rate
   3. Compute the daily safe dose if risk scales not with mass but with mass specific metabolic rate
   4. What if dosage depends on both body mass and mass specific metabolic rate.

http://www.life.illinois.edu/mcb/441/private/sample_exams/exam_01.html

1. Assuming that the mass-specific metabolic rate of a 10 kg child is twice as high as that of a 100 kg adult, what is the proper drug dosage for a child if the optimal dose for a 100 kg adult is 100 mg.

Surface to volume ratio

1. effects of body size on body structure and physiology
   A. temperature regulation
   B. water balance
   C. bone and muscle structure
   D. relative strength
   E. structural integrity

2/3 and Rubner’s Law

1. Surface area to volume scales
   A. SA/V ~ r^{2/3}
2. Is BMR a function of relative SA?
   A. Smaller animals have greater SA
   B. But scaling holds across plants, animals, endo- and ectotherms
1. Slope (b) of MR-mass equations ranges ~ 0.62 – 0.83
2. Encompasses both 0.66 (2/3) and 0.75 (3/4)

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Kleiber’s Law

1. \( V_O_2 = 0.676M_b^{0.75} \)
2. \( \log (\text{metabolic rate}) = 0.75 \log (\text{mass}) \)
3. As body mass increases four-fold, metabolic rate increases three-fold.
4. Why is the exponent 0.75 instead of 0.67?

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Fractals

1. According to West et al. (1999) the exponents that are multiples of 1/4 are a consequence of the fractal properties of branching networks so prevalent in organisms and the natural selection for the minimal time of transport within these networks.
2. At its most basic level, the exponents that are multiples of 1/4, occur because biological systems operate within 4 dimensions (length to the third power, plus time) rather than the 3 dimensions of Euclidean geometry.

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Heartbeat Frequency

1. Our pulse is about 70 bpm
2. Elephants, about 40
3. Hummingbirds and small bats at about 1200
4. Increase in pulse exactly accounts for increased oxygen needs

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TABLE 7.4  Breathing heart rate and heart size relative to body weight, in seven species of mammals

<table>
<thead>
<tr>
<th>Species</th>
<th>Breathing heart rate</th>
<th>Heart size per unit of body weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Giant panda (Jin Lin)</td>
<td>80</td>
<td>4.7</td>
</tr>
<tr>
<td>Horse (Horse)</td>
<td>47</td>
<td>7.5</td>
</tr>
<tr>
<td>Human (Human)</td>
<td>78</td>
<td>8.2</td>
</tr>
<tr>
<td>Domestic dog (Dog)</td>
<td>106</td>
<td>9.2</td>
</tr>
<tr>
<td>Domestic cat (Cat)</td>
<td>139</td>
<td>4.1</td>
</tr>
<tr>
<td>Rat (Rat)</td>
<td>343</td>
<td>0.9</td>
</tr>
<tr>
<td>Mouse (Mouse)</td>
<td>585</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Sources: After K. Franks and P. Wootton (1986).
1. Metabolic time
   A. for mammals metabolic time is proportional to mass^{0.25}
   B. mammals usually get about 1-2 billion heartbeats,
   C. humans do significantly better though (by about a factor of 3)

Ecological Consequences

1. 400 lbs of vole will consume more resources than 400 lbs of rhino in the same area

2. In calculating the carrying capacity of an area, both number and size of animals must be taken into account.

HWA Figure 5.6

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**TABLE 5.5 Biomasses of populations of selected herbivores living in mixed communities in African national parks** Species are listed in order of increasing individual size. These species were chosen for listing because they are statistically about average in population biomass for their body sizes.

<table>
<thead>
<tr>
<th>Species</th>
<th>Average biomass of whole population per square kilometer (kg/km²)</th>
<th>Average individual body weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oribi (Ourebia ourebi)</td>
<td>44</td>
<td>13</td>
</tr>
<tr>
<td>Gray duiker (Sylvicapra grimmia)</td>
<td>62</td>
<td>16</td>
</tr>
<tr>
<td>Gray reedbuck (Pelecanus cappuciosus)</td>
<td>105</td>
<td>25</td>
</tr>
<tr>
<td>Warthog (Phacochoerus amhicus)</td>
<td>95</td>
<td>69</td>
</tr>
<tr>
<td>Waterbuck (Kobus ellipsiprymnus)</td>
<td>155</td>
<td>210</td>
</tr>
<tr>
<td>Greater kudu (Tragelaphus strepsiceros)</td>
<td>200</td>
<td>215</td>
</tr>
<tr>
<td>Plains zebra (Equus burchelli)</td>
<td>460</td>
<td>275</td>
</tr>
<tr>
<td>White rhino (Ceratotherium simum)</td>
<td>2400</td>
<td>1900</td>
</tr>
<tr>
<td>African elephant (Loxodonta africana)</td>
<td>1250</td>
<td>3900</td>
</tr>
</tbody>
</table>

Source: After Owen-Smith 1988.