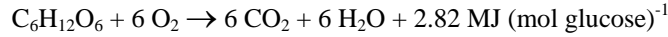


**EFB 462/662 Animal Physiology: Environmental & Ecological**  
**How much water do I need?**

One can use Henry's Law and some simple stoichiometry to estimate how much water a gill must process to extract oxygen.

We remember first that there is a strict stoichiometry that governs the oxidation of glucose to carbon dioxide, water and energy:



We may use the stoichiometry to formulate a molar energy production rate. The molar energy production for glucose, for example, is  $2.82 \text{ MJ (mol glucose)}^{-1}$ . Let us designate this is  $Q_{Gl}$ . There is also a molar energy production for oxygen: because 6 moles of oxygen are consumed for every mole of glucose consumed, oxygen's molar energy production ( $Q_{O_2}$ ) is one-sixth of that for glucose, or  $0.47 \text{ MJ (mol O}_2\text{)}^{-1}$ :

We remember also the fundamental definition of metabolic rate as a *power*, that is, a *rate of energy utilization per time*. We express this with the symbol  $\dot{Q}$ . In SI units, the unit of power is the *watt* defined as an energy usage rate of  $1 \text{ J s}^{-1}$ . An energy production rate, therefore, implies a molar consumption rate for both glucose and oxygen. Let us designate a molar consumption rate as  $\dot{M}$ , which has units of  $\text{mol s}^{-1}$ .

The glucose (or oxygen) necessary to yield 1 joule is simply the inverse of the molar energy production. For glucose, it is:

$$\frac{M_{Gl}}{2.82 \text{ MJ}} \cdot \frac{1 \text{ MJ}}{10^6 \text{ J}} = 3.54 \cdot 10^{-7} \frac{M_{Gl}}{\text{J}}$$

For oxygen, it is:

$$\frac{M_{O_2}}{0.47 \text{ MJ}} \cdot \frac{1 \text{ MJ}}{10^6 \text{ J}} = 2.12 \cdot 10^{-6} \frac{M_{O_2}}{\text{J}} = 2.11 \frac{\mu\text{M}_{O_2}}{\text{J}}$$

It follows that a particular molar consumption rate,  $\dot{M}$  is required to support a particular metabolic rate,  $\dot{Q}$ . By the above equation,  $2.12 \mu\text{moles}$  of oxygen must be consumed each second to support a metabolic rate of 1 watt.

How much water is needed to supply oxygen at this rate?

The solubility coefficient for oxygen in water,  $\alpha_{O_2}$ , at  $20^\circ\text{C}$  is about  $13.7 \mu\text{mol l}_{\text{H}_2\text{O}}^{-1} \text{ kPa}^{-1}$  (SI units). By Henry's law, the molar concentration of oxygen in water is:

$$[\text{O}_2] = \alpha_{O_2} \cdot p_{O_2}$$

where  $p_{O_2}$  is the oxygen partial pressure. At sea level atmospheric pressure ( $101.525 \text{ kPa}$ ), the oxygen partial pressure is the mole fraction of that, or  $0.2095 \cdot 101.525 = 21.3 \text{ kPa}$ . According to Henry's law, the molar concentration of oxygen will be  $(13.7 \mu\text{mol l}_{\text{H}_2\text{O}}^{-1} \text{ kPa}^{-1}) \cdot 21.3 \text{ kPa} = 291 \mu\text{mol l}^{-1}$ .

To support a metabolic rate of 1 watt, the volume of water that must be processed each second,  $\dot{V}_{H_2O}$ , ( $\text{l s}^{-1}$ ) is therefore:

$$\dot{V}_{H_2O} = \frac{\dot{M}_{O_2}}{[\text{O}_2]} = \frac{2.12 \mu\text{mol} \cdot \text{s}^{-1}}{291 \mu\text{mol} \cdot \text{l}^{-1}} = 0.0073 \cdot \frac{\text{l}}{\text{s}} = 7.3 \cdot \frac{\text{ml}}{\text{s}}$$

This is a minimum figure, of course, assuming that extraction of oxygen is 100% efficient. If only half the oxygen can be extracted, twice the volume of water must be processed.