Problem Set 8.1
Energy Balance

Conversion Factors: 2.54 cm = 1 in.; 1 lb = 453.6 g; 16 oz = 1 lb; 1 J = 0.239 cal; 1 W = 1 J s^{-1}; °F = 9/5 × °C + 32; 1 fluid oz = 0.029574 L; 1 L = 1.0566 qt

1. Using the Atwater Factors, calculate the energy content of 100 g (3/4 cup) of vanilla ice cream of composition 4% protein, 13% fat, and 21% carbohydrate. Percent composition is by weight, i.e., 4% is 4 g per 100 g ice cream.
2. Raw, long-grain brown rice has the following composition (http://www.ars.usda.gov):

Nutrients	Grams per 100 g
Water	10.37
Protein	7.94
Fat	2.92
Carbohydrate	77.24
Ash	1.53

   Using the Atwater Factors, calculate the total energy per 100 g of dry rice, in both kJ and kcal.
3. According to NHANES 2011–2012 (National Health and Nutrition Examination Survey), the average diets of 20–29-year-old people in the United States has the following composition of macronutrients (Table PS 8.1.2):
   Complete the table by calculating how much energy is supplied by each macronutrient and what fraction this constitutes of the whole, using the Atwater factors. Why do you suppose that females, on average, consume fewer calories than males?
4. According to the USDA, the following data were obtained for whole wheat flour (Table PS 8.1.3):
   What is the apparent Atwater Factor for these macronutrients based on these numbers? Why are they not identical to the Atwater Factors of 4, 4, and 9 kcal per g? See http://www.nutribase.com/449.html.
5. Consider a 22-year-old male who is 5′10″ tall and weighs 175 lb.
   A. Estimate his body surface area using the Dubois equation.
   B. Using Figure 8.6.3, estimate the BMR in energy per day.
   C. Compare the BMR in part B to that obtained from the Harris–Benedict equation.
   D. Add 25% for activity to the BMR to estimate normal energy requirements. This varies widely depending on the activity level. This is the estimated energy requirement and estimated energy consumption.
   E. The RDA (recommended dietary allowances) for protein is 0.8 g per kg of body weight per day. Estimate the RDA for protein for this individual.
   F. According to the USDA (http://www.ars.usda.gov), 4 oz of lean ground beef (10% fat) contains 22.60 g of protein. How many ounces of hamburger would supply this person with the RDA for protein?
   G. Using the Atwater Factor for protein, what fraction of the dietary consumption is made up from the recommended level of protein?
6. Adipose tissue varies in its composition, both in terms of water content, fat, and protein content, and distribution of fatty acyl chains in the lipids. Omental fat biopsies obtained from patients undergoing surgery were analyzed and found to contain about 10% water, 87% fat, and 2% protein (L.W. Thomas, *Exp. Physiol.* **47**:179–188, 1962). Calculate the energy equivalent of 1 lb of adipose tissue in the body. This would be the excess energy expenditure necessary to lose 1 lb of fat.
7. In obese persons, biopsies of fat show lower water content than biopsies of fat from leaner persons. Give a reasonable explanation of why this should be the case.
8. Based on your answer to PS 8.1 #6, about how much extra oxygen must you consume to lose 1 lb of adipose tissue?
9. Although the rate of oxygen consumption varies with body size, composition, and age, an average figure is about 250 mL min^{-1}. Based on this oxygen consumption, and using an average value for the energy equivalent of O_2, what is a typical BMR in kcal per day? What is this BMR in watts? Based on this figure, how much cooling would you need to keep an auditorium with 500 people at a constant temperature?
10. Consider a male person 20 years of age who is 5′8″ tall and weighs 160 lb.
    A. If the basal oxygen consumption is 3.5 mL O_2 per minute per kg of body weight (=1 MET), what is the resting energy expenditure?
    B. Calculate their BMR from the Harris–Benedict formula. How do the values from A and B compare?

DOI: http://dx.doi.org/10.1016/B978-0-12-800883-6.00083-5

TABLE PS 8.1.2

Macronutrients	Males	Females	Calories (kCal or kJ)		% of energy	
			Males	Females	Males	Females
Protein (g)	102.9	72.1				
Carbohydrate (g)	332	255				
Fat (g)	102.3	75.5				
Total (g)						

TABLE PS 8.1.3

Macronutrients	g/120 g	kcal/120 g	Atwater Factor
Protein	16.9	59.8	
Carbohydrate	87.1	329	
Total fat	2.2	18.8	

11. If n is known, then p is known from Eqn (8.6.6). If p is known, then Eqn (8.6.7) are two equations in two unknowns. Solve Eqns (8.6.6) and (8.6.7) to derive expressions for c and f in terms of V_{CO_2}, V_{O_2}, and n.
12. Solve PS 8.1 #11 first. A middle-aged person walks for 2 hours on a treadmill at 4 mph. He voided his bladder at the beginning of the exercise and again at the end. The second urine sample was 130 mL, and its nitrogen concentration was 11.1 mg mL^{-1}. The total oxygen consumed during the 2 hours was 125.1 L, and the CO_2 produced was 97.0 L.
    A. Calculate the total urinary nitrogen and estimate g of protein utilized during the period.
    B. Calculate the grams of carbohydrates and fats consumed during the period.
13. Lavoisier determined metabolic rate of experimental animals by surrounding them with insulated ice and measuring the rate at which the ice melted. The heat of fusion of ice is 80 cal g^{-1}.
    A. If your oxygen consumption is 250 mL min^{-1}, at what rate can you melt ice?
    B. Assume you weigh 150 lb. The overall heat capacity of the human body is about 3500 J kg^{-1} $°C^{-1}$. You cool down 8 oz of coke to 0°C and in it is still floating 50 g of ice. How much will drinking that coke at 0°C alter your body temperature, assuming no compensatory mechanisms and instantaneous thermal equilibrium?
14. Assume you weigh 170 lb and your heat capacity is 3500 J kg^{-1} $°C^{-1}$; your oxygen consumption is 1 MET = 3.5 mL kg^{-1} min^{-1} and your resting temperature is 37°C. Your "friends" try to play a joke on you by covering you with a layer of metallic film that prevents all routes of energy transfer between you and the environment: no radiative, conductive, convective, or evaporative loss of energy can occur. Assuming your metabolic rate does not change with temperature (an invalid assumption), how long will it take before your temperature rises from 37°C to 39°C?
15. Assume you consume a typical American diet containing 20% of calories from protein, 40% from fat, and 40% from carbohydrates. Assume further that you caloric intake is 2800 kcal day^{-1} and that you maintain a steady state of both energy balance and protein balance. Estimate
    A. urinary nitrogen excretion, per day;
    B. O_2 consumed, per day;
    C. CO_2 produced, per day;
    D. the average respiratory quotient.
16. Flying Dog Brewery makes a beer called Doggie Style that is 4.7% ethanol by volume and contains 11.4 g of carbohydrate per 12 oz bottle. Using the Atwater Factors, calculate the calories in a 12-oz bottle of this beer. The density of alcohol is 0.785 g cm^{-3}.
17. In Chapter 2.11, we calculated that the ATP yield from glucose was 32 moles of ATP per mole of glucose and the ATP yield from tripalmitin was 336.5 moles of ATP per mole of tripalmitin. Compare these yields to the Atwater Factors. Are the ATP yields proportional to the energy of combustion? The molecular weight of glucose is 180 g mol^{-1}. The molecular weight of tripalmitin is 807.3 g mol^{-1}.
18. The heat of combustion for palmitic acid is 9977.9 kJ mol^{-1} for the crystalline form, 10,031.3 kJ mol^{-1} for liquid form, and 10,132.3 kJ mol^{-1} for the gas form. The heat of combustion of glycerol is 1655.4 kJ mol^{-1} for the liquid.
    A. Write a balanced chemical reaction for the complete oxidation of palmitic acid ($C_{16}H_{32}O_2$).
    B. Write a balanced chemical reaction for the complete oxidation of glycerol ($C_3H_8O_3$).
    C. Why is the energy of combustion different for crystalline, liquid, and gas forms of palmitic acid? Which should be used in biochemical calculations?
    D. What is the energy equivalence of O_2 when palmitic acid is oxidized?
    E. What is the energy equivalence of O_2 when glycerol is oxidized?

F. What is the predicted Atwater Factor for palmitic acid?
G. What is the predicted Atwater Factor for glycerol?

19. An indication of adiposity is the **body mass index**, **BMI**. It is defined as the mass in kilograms divided by the height in meters squared: $\text{BMI} = \text{kg m}^{-2}$. Although this obviously does not directly measure body fat, it was found that this variable best predicts chronic diseases associated with obesity. $\text{BMI} > 30$ indicates obesity; $\text{BMI} > 40$ indicates morbid obesity; $\text{BMI} < 16$ indicates dangerous underweight.
A. For a person 5′8″ and 180 lb, calculate the BMI. Is this person obese?
B. For a person 5′2″ tall and 100 lb, calculate the BMI. Is this person seriously underweight?
C. Do you think BMI is a useful measure of obesity? Why or why not?

20. Suppose a person has a BMR of 1770 kcal day^{-1}. The person consumes a meal containing 700 kcal. The thermic effect of the food is given as $179.5\, t\, e^{-t/1.3}$ where t is time in hours, and the units of the constant, 179.5, are kJ h^{-2}. This constant is a fitted parameter that varies with individuals—it is NOT a biological invariant.
A. Calculate the thermic effect by integrating the equation from 0 to 8 hours (negligible thermic effect remains after 6 hours but we will do it for 8 to be certain).
Hint:

$$\int A\, x\, e^{\frac{x}{C}}\, dx = -AC^2\left(\frac{x}{C} + 1\right)e^{\frac{x}{C}}$$

B. What is the fraction of calories of the meal expended in the thermic effect?
C. Prove the hint in part A by taking the derivative of both sides of the equation.