

Solutions to Problems: CH.4

Section 4.1

4.1. (I) How much work must a car produce to drive 150 km if an average force of 500 N must be maintained to overcome friction?

Ans. Work = Force in the direction of motion times displacement. The displacement is 150 kilometers. 1 kilometer = 1000m, therefore the displacement = 150×10^3 meters.

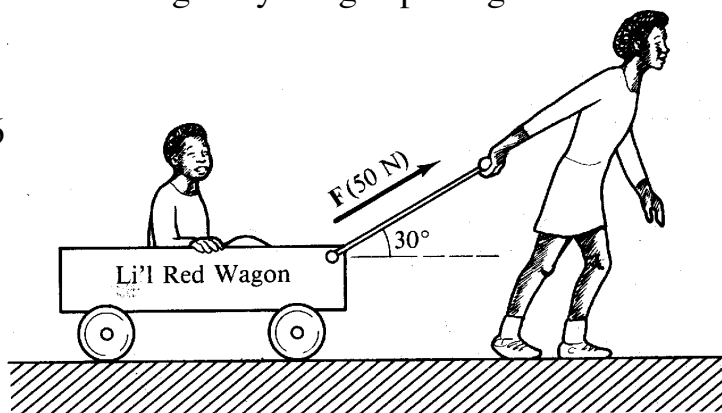
$$W = F\Delta X = 500 \text{ N} (150 \times 10^3 \text{ m}) = 7.5 \times 10^7 \text{ joules}$$

4.2. (II) Calculate the work done by a 55-kg person in climbing a flight of stairs 2.0 m high.

Ans. Work = $F\Delta X$ = weight x height = $mgh = 55 \text{ kg} (9.8 \text{ m/sec}^2) 2\text{m} =$
1,078 joules = 1,080 joules

4.3. (III) How much work is done to the wagon by the girl pulling her brother shown in **Figure 4.16**, if she travels 25 m?

Fig. 4.16



Ans. Baby step 1: calculate the force in the direction of motion.
 $\cos 30^\circ (50 \text{ N}) = 43.3 \text{ Newtons}$

Baby step 2: Use our Work equation.

Ans. Work = $F\Delta X = 43.3 \text{ N} (25 \text{ m}) =$ **1,080 joules**

Section 4.2

4.4. (I) Calculate a) the kinetic energy of a 50-kg athlete running at a speed of 3.0 m/sec with the kinetic energy of a 25-kg cheetah running at 30 m/sec. b) Compare the kinetic energy of the cheetah to the kinetic energy of the athlete.

$$\text{Kinetic energy of the person: } K.E. \equiv \frac{1}{2}mv^2 = \frac{1}{2}50\text{kg}\left(3\frac{\text{m}}{\text{s}}\right)^2 = 225 \frac{\text{kg}\cdot\text{m}^2}{\text{s}^2}$$

$$\text{Kinetic energy of the cheetah: } K.E. \equiv \frac{1}{2}mv^2 = \frac{1}{2}25\text{kg}\left(30\frac{\text{m}}{\text{s}}\right)^2 = 11,250 \frac{\text{kg}\cdot\text{m}^2}{\text{s}^2}$$

Comparing the kinetic energy of the person cheetah to the kinetic energy of the person:

$$\text{Ans. } \frac{K.E.\text{cheetah}}{K.E.\text{person}} = \frac{11,250 \text{ joules}}{225 \text{ joules}} = 50$$

Therefore the cheetah has **50 times** the kinetic energy of the athlete.

4.5. (I) a) How much energy in kilocalories is expended against gravity alone by a 75-kg man in climbing 1500 m up a mountain? b) Convert the energy to joules.

$$\text{Ans. Gravitational Potential Energy} = mgh = 75 \text{ kg}(9.8 \text{ m/s}^2)(1500 \text{ m}) = \mathbf{1.10 \times 10^6 \text{ joules.}}$$

4.6. (I) How long can you play tennis on the energy from a 10-g pat of butter? (*See tables 4.1 and 4.2.*).

Baby step 1: Determine the amount of energy in the 10 grams of **butter**.

$$7.2 \frac{\text{kcal}}{\text{g}}(10\text{g}) = 72\text{kcal}$$

Baby step 2: From table 4.2 we see that the energy consumption rate while playing tennis is $\frac{6.3\text{kcal}}{\text{minute}}$. The phrase ‘energy consumption rate’ means power.

Baby step 3: Solve the power equation for time.

$$\text{Power} \equiv \frac{\text{Energy}}{\text{time}} \quad \text{Therefore } \text{time} = \frac{\text{Energy}}{\text{power}}$$

$$\text{Ans. } \text{time} = \frac{72\text{kcal}}{\frac{6.3\text{kcal}}{\text{min}}} = 11.4\text{minutes}$$

Section 4.2 continued

4.7. (I) How many minutes of lecture can you sit through on the energy supplied by 32 g of peanuts? This is the average amount in a vending machine pack. (See tables 4.1 and 4.2.).

Baby step 1: Determine the amount of energy in the 32 grams of *Peanuts*.

$$5.73 \text{ kcal/g} (32 \text{ g}) = 183 \text{ kcal.}$$

Baby step 2: From table 4.2 we see that the energy consumption rate while sitting through a lecture is $\frac{3 \text{ kcal}}{1 \text{ min}}$. The phrase 'energy consumption rate'

means power.

Baby step 3: Solve the power equation for time.

$$\text{Ans. } 183 \text{ kcal} \cdot \left(\frac{1 \text{ min.}}{3 \text{ kcal}} \right) = 61 \text{ minutes of lecture}$$

4.8. (II) If a 0.5 kg. baseball is caught by a person whose hand recoils 0.30 m, calculate the average force on the person's hand while stopping the ball. (The initial speed of the baseball is 44.7 m/sec). Assume that all of the kinetic energy of the baseball is used in doing work, moving the recoiling hand.



speed = 44.7 m/s

Mass = 0.50 kg

The kinetic energy of the baseball is:

$$\text{Ans. } KE \equiv \frac{1}{2}mv^2 = \frac{1}{2}(.5 \text{ kg}) \left(44.7 \frac{\text{m}}{\text{s}} \right)^2 = 500 \frac{\text{kg} \cdot \text{m}^2}{\text{s}^2}$$

4.9. (II) Calculate the gravitational potential energy of the water in a lake of volume 100 km^3 (mass = $1.0 \times 10^{14} \text{ kg}$). The lake has an average height of 50 m above the hydroelectric generators at the base of the dam holding the water back.

$$\text{Ans. } G.P.E. \equiv mgh = 1.0 \times 10^{14} \text{ kg} \cdot 9.8 \frac{\text{m}}{\text{s}^2} \cdot 50 \text{ m} = 4.9 \times 10^{16} \frac{\text{kg} \cdot \text{m}^2}{\text{sec}^2}$$

$$4.9 \times 10^{16} \text{ joules}$$

4.11. (II) (a) Using the data in Table 4.2, calculate the number of kilocalories needed to climb 232 stair steps (116 steps per minute for 2 min). (b) Calculate the gain in gravitational potential energy for a 50-kg person if each step is 0.18 m high. Convert this answer to Kcal and compare your result with the answer to part (a). Explain why the energy found in part (a) is larger than that found in part (b).

$$\text{Ans. 4.11a. } 9.8 \frac{\text{kcal}}{\text{min}} \cdot 2 \text{ min} = 19.6 \text{ kcal}$$

$$\text{Ans. 4.11b. } GPE \equiv mgh = 50 \text{ kg} \cdot 9.8 \frac{\text{m}}{\text{s}^2} \cdot \left(0.18 \frac{\text{m}}{\text{step}} \right) \cdot 232 \text{ steps} = 20,462 \text{ joules}$$

$$20,462 \text{ joules} \cdot \frac{1 \text{ kcal}}{4184 \text{ joules}} = 4.89 \text{ kcal}$$

4.12. (II) (a) How many kilocalories are required to walk 8.0 hr per day, as many nurses do on their jobs? (b) If the remainder of the day is spent sitting at rest for 8.0 hr and (c) Sleeping for 8.0 hr (d) What total number of kilocalories would be needed for the entire day?

Ans. 4.12.a Energy consumed walking during an 8.0 hr shift.

$$3.8 \frac{\text{kcal}}{\text{min}} \cdot 60 \frac{\text{min}}{\text{hr}} \cdot 8 \frac{\text{hr}}{\text{shift}} = 1824 \frac{\text{kcal}}{\text{shift}}$$

Ans. 4.12.b Energy consumed sitting at rest for 8.0 hours.

$$1.7 \frac{\text{kcal}}{\text{min}} \cdot 60 \frac{\text{min}}{\text{hr}} \cdot 8 \text{ hr} = 816 \text{ kcal}$$

Ans. 4.12.c Energy consumed sleeping for 8.0 hours.

$$1.2 \frac{\text{kcal}}{\text{min}} \cdot 60 \frac{\text{min}}{\text{hr}} \cdot 8 \text{ hr} = 576 \text{ kcal}$$

Ans. 4.12.d. Total energy consumed.

Total amount of energy is $1824 \text{ kcal} + 816 \text{ kcal} + 576 \text{ kcal} = 3216 \text{ kcal}$

Section 4.4

4.18. (II) Surprisingly little advantage is gained by getting a running start in a downhill race. To demonstrate this, calculate the final speed of a skier who skis down a hill 80-m-high with negligible friction (a) if her initial speed is zero; (b) if her initial speed is 3.0 m/sec. [The final speed found in part (b) is larger than in part (a), but by far less than 3.0 m/sec!]

We will use conservation of energy to solve this problem

Because we are told that we can ignore friction, the total energy at the top of the hill will equal the total energy at the bottom of the hill.

Ans. 4.18a. Starting from rest.

GPE at top of hill = Kinetic energy at the bottom of the hill.

$$mgh = \frac{1}{2}mv^2 \quad \text{Therefore, } v = \sqrt{2 \cdot g \cdot h}$$

$$v = \sqrt{2 \cdot 9.8 \frac{m}{s^2} \cdot 80m} = 39.6 \frac{m}{s}$$

Ans. 4.18b. Initial speed is 3.0 m/s.

$$\frac{1}{2}mv_{top}^2 + mgh_{top} = \frac{1}{2}mv_{bottom}^2$$

Divide everything by the mass.

$$\frac{1}{2}v_{top}^2 + gh_{top} = \frac{1}{2}v_{bottom}^2$$

$$\frac{1}{2}3^2 + 9.8 \frac{m}{s^2} \cdot 80m = \frac{1}{2}v_{bottom}^2$$

$$v = 39.7 \frac{m}{s} \quad \text{Only 0.1 meter per second faster than starting from}$$

rest. Do the downhill skiers know this?

4.22. (I) What is the useful power output in a) watts and b) horsepower of a person who does 2.5×10^6 J of useful work in 4.0 hr?

$$Power \equiv \frac{\text{Energy or work}}{\text{time}}$$

$$\text{Ans. 4.22a. } Power = \frac{2.5 \times 10^6 \text{ joules}}{4 \text{ hrs}} \left(\frac{1 \text{ hr}}{3600 \text{ sec}} \right) = 174 \frac{\text{joules}}{\text{sec}} = 174 \text{ watts}$$

Ans. 4.22b. There are 746 watts in 1.0 horsepower.

$$174 \text{ watts} \frac{1 \text{ hp}}{746 \text{ watts}} = 0.233 \text{ horsepower}$$

4.24. (I) What is the efficiency of an athlete who consumes 3000 kcal of food and does 2.5×10^6 J of useful work?

$$Efficiency \equiv \frac{\text{Work done}}{\text{total energy supplied}} * 100\%$$

$$\text{Baby step 1. } Efficiency \equiv \frac{2.50 \times 10^6 \text{ joules}}{3000 \text{ kcal}} * 100\%$$

Baby step 2. Notice that we have energy in joules and in kcal. In order to compare them, they have to be in the same set of units. First convert the 3000 kcal to calories and then joules.

$$\frac{2.5 \times 10^6 \text{ joules}}{3000 \text{ kcal}} \left(\frac{1 \text{ kcal}}{1000 \text{ cal}} \right) \left(\frac{1 \text{ cal}}{4.2 \text{ joules}} \right) 100\% = 19.9\%$$

4.25. (I) Calculate the efficiency of a light bulb that consumes 60 W of electric power and radiates 10 W of visible light.

$$Efficiency \equiv \frac{\text{power output}}{\text{power input}} \cdot 100\%$$

$$Efficiency \equiv \frac{10 \text{ W}}{60 \text{ W}} \cdot 100\% = 16.7\%$$

Today's light emitting diode bulbs, (LED), are much more efficient and economical.

4.26. (II) How much does it cost to operate a 1.0-W electric clock for a year if electricity costs 11¢/kWh?

Baby step 1. Determine the amount of energy used in a year.

$$Power \equiv \frac{Energy}{time} \quad Energy = Power \cdot time$$

$$Energy = 1 \frac{joule}{sec} \cdot 365 days \cdot \frac{24 hrs}{day} = 8,760 watt \cdot hrs$$

Baby step 2. Convert units to kilowatt-hrs.

$$8760 watts \cdot \frac{1kwatt}{1000watts} = 8.76kwatt \cdot hrs$$

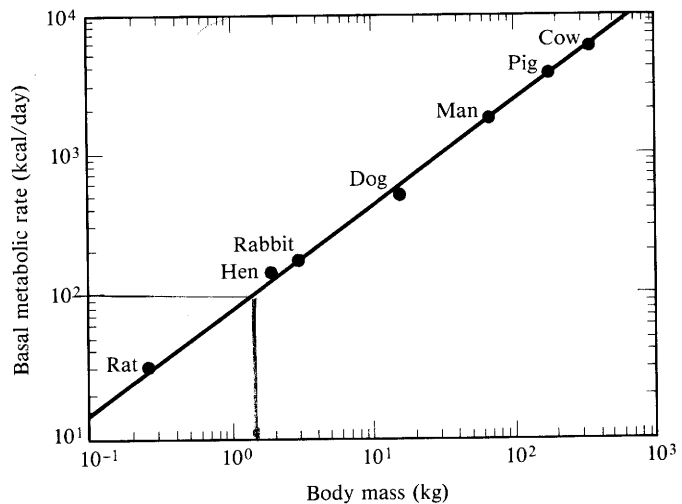
Baby step 3. Determine the cost.

$$8.76kwatt \cdot hrs \cdot \frac{11cents}{kwatt \cdot hr} = 96.4cents$$

Section 4.5

4.32. (1) Use **Figure 4.14** to estimate the number of kilocalories per day needed by a 1.5-kg premature baby. From this, calculate the number of liters of oxygen consumed per day. Approximately 4.9 kcal of energy are produced for each liter of oxygen consumed. (Note: In practice, the oxygen supplied to premature babies is regulated on the basis of periodic sampling of the oxygen content of the baby's blood. Brain damage can be caused to the baby by either too little or too much oxygen.)

Figure 4.14 A plot of BMR versus mass for various animals shows a straight-line relationship on a logarithmic scale indicating $\text{BMR} \propto m^{3/4}$. The BMRs of humans of different masses also follow this relationship. The data point presented is for a man of average mass (70 kg). From J. Cameron and J. Skofronick, *Medical Physics*, (Wiley-Interscience, New York, 1978), by permission.



4.32a. Baby step 1. Study figure 4.14 to estimate the number of kcal/day required by the 1.5 kg baby: 100 kcal/day

4.32b. Baby step 2. Calculate the number of liters of oxygen consumed per day. Treat this as a unit conversion problem.

$$100 \frac{\text{kcal}}{\text{day}} \cdot \frac{1 \text{ liter}}{4.9 \text{ kcal}} = 20.4 \frac{\text{liters}}{\text{day}}$$

4.33. (I) (a) What percentage of the body's energy is used by the heart and skeletal muscles when resting? (b) How many kilocalories per minute are required for the heart and skeletal muscles? Please refer to *Table 4.4*.

TABLE 4.4 / BASAL METABOLIC RATE AND OXYGEN CONSUMPTION RATES^a

Organ	Power Consumed at Rest		Oxygen Consumption (ml O ₂ /min)	Percent of BMR
	(kcal/min)	(W)		
Liver and spleen	0.33	23	67	27
Brain	0.23	16	47	19
Skeletal muscle	0.22	15	45	18
Kidney	0.13	9	26	10
Heart	0.08	6	17	7
Other ^b	0.23	16	48	19
Totals	1.22	85	250	100

^aIn resting 65-kg male.

^bIncludes the digestive tract, smooth muscle, skin, etc.

Based on J. Cameron and J. Skofronick, *Medical Physics* (Wiley-Interscience, New York, 1978), by permission.

Ans. 4.33a. $18\% + 7\% = 25\%$

Ans. 4.33b. $0.08 \text{ kcal/min} + 0.22 \text{ kcal/min} = 0.30 \text{ kcal/min}.$

4.34. (II) (a) Calculate the energy in kilocalories needed to play tennis for 2.0 hr.
(b) What percentage of this energy would be supplied by a soft drink containing 50 g of sugar?

Ans. 4.34a. $6.3 \text{ kcal/min}(120 \text{ min}) = 756 \text{ kcal}$

Ans. 4.34b From table 4.1 we know that sugar yields 4 kcal/g .

Baby Step 1. Determine the energy supplied by 50 grams of sugar.
 $4 \text{ kcal/g}(50\text{g}) = 200 \text{ kcal}$

Baby Step 2. Determine the percentage of energy supplied by the sugar.

$$200 \text{ kcal}/756 \text{ kcal} (100\%) = 26.5 \%$$

4.35. (II) It is reasonable to assume that the body obtains as much energy from breaking down its own fatty tissue as it does from digesting fat. How many grams of fat will be lost by a person who swims 2.0 hr, sleeps 8.0 hr, and sits at rest the remainder of the day, if he consumes 2000 kcal? See table 4.1 for caloric content of lard (fat).

Swimming for 2 hrs: $6.8 \text{ kcal/min} (120\text{min}) = \mathbf{816 \text{ kilocalories}}$

Sleeping for 8 hrs: $1.2 \text{ kcal/min} (480 \text{ min}) = \mathbf{576 \text{ kilocalories}}$

Sitting at rest for 14 hrs: $1.7 \text{ kcal/min}(14\text{hr})(60\text{min/hr}) = \mathbf{1428 \text{ kilocalories}}$

Total energy used = $816 + 576 + 1428 = \mathbf{2820 \text{ kilocalories}}$

Remember that the swimmer consumed 2,000 kcal of food.

The extra energy from fat is $2,820 - 2,000 = 820 \text{ kcal}$.

From Table 4.1 we know that there are 9.3 kcal of energy in every gram of fat.

$$820\text{kcal} \cdot \frac{1\text{g}}{9.3\text{kcal}} = 88.2 \text{ grams of fat}$$