Table 2.2 The Commonly Used Prefixes in the Metric System

Prefix	Symbol	Meaning	Power of 10 for Scientific Notation
mega	M	1,000,000	10^6
Kilo	k	1,000	10^3
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	u	0.000001	10^{-6}
nano	n	0.000000001	10^{-9}

Table 2.3 The Metric System for Measuring Length

Unit	Symbol	Meter Equivalent
kilometer	km	1000 m or 10^3 m
meter	m	1 m or 1 m
decimeter	dm	0.1 m or 10^{-1} m
centimeter	cm	0.01 m or 10^{-2} m
millimeter	mm	0.001 m or 10^{-3} m
micrometer	um	0.000001 m or 10^{-6} m
nanometer	nm	0.000000001 m or 10^{-9} m

Table 2.4 The Relationship of the Liter and Milliliter

Unit	Symbol	Equivalence
liter	*L*	$1\,L = 1000\,mL$
milliliter	*mL*	$\frac{1}{1000}\,L = 10^{-3}\,L = 1\,mL$

Table 2.5 The Most Commonly Used Metric Units of Mass

Unit	Symbol	Gram Equivalent
kilogram	kg	1000 g = 10^3 g = 1 kg
gram	g	1 g
milligram	mg	0.001 g = 10^{-3} g = 1 mg

B

Conversion Factors

Distances

1 ft = 12 in
1 yd = 3 ft
1 mile = 5,280 ft
1 mile = 1,760 yd
1 m = 100 cm
1 km = 1,000 m
1 in = 2.54 cm
1 yd = .9144 m
1 mile = 1.62 km
1 m = 39.37 in
1 m = 3.28 ft
1 km = 1,093.6 yd
1 km = .62 miles

Speeds

1 mph = 1.47 ft/sec
1 mph = 88 ft/min
60 mph = 88 ft/sec
1 km/hr = .28 m/sec
1 km/hr = 16.7 m/min
1 mph = .45 m/sec
1 mph = 26.8 m/min
1 mph = 1.62 km/hr
1 km/hr = .62 mph
1 km/hr = .91 ft/sec

Weights

1 oz = 28 g
1 lb = 454 g
1 g = 1,000 mg
1 kg = 1,000 g
1 kg = 1 kp
1 kg = 2.2 lb
1 kg = 9.8 N.

Volumes (O_2, CO_2, N_2, or Blood)

1 oz = 29.57 ml
1 quart = 1.11 L
1 dl = 100 ml
1 L = 1,000 ml

Work Units

1 kcal = 426.8 kgm
.005 kcal = 1 ml O_2
5 kcal = 1 L O_2
1 kgm = 1.8 ml O_2
1 kcal/kg/hr = 1 MET
1.8 ml O_2/kg/in = 1 kgm/min (for leg ergometer only)
1 kg body wt/m/min = 1.8 ml O_2 (for leg ergometer only)

Workload Units

1 Watt = 6.0 kgm/min
1 MET = 3.5 ml O_2/kg/min
1 kgm/min = .1635 Watts
1.8 ml O_2/kg/min = 1 m/min
1 HP = 746 Watts
1 L O_2/min = 5 kcal/min
2 ml O_2 = 1 kgm (for leg ergometers)
3 ml O_2 = 1 kgm (for arm ergometers)
0.35 ml O_2/kg/min = 1 step/min (for bench stepping)
0.1 ml O_2/kg/min = 1 m/min (for walking)
0.2 ml O_2/kg/min = 1 m/min (for running)

Nutrition Units

4 kcal = 1 g protein
9 kcal = 1 g fat
4 kcal = 1 g carb
7 kcal = 1 g alcohol
28 g = 1 oz
.005 kcal = 1 ml O_2

*Units of measure in boldface type are the preferred units in the *Systeme International.*

*Traditionally, in the United States, English units of measurement have been used, and we have presented equivalents for various units. However, practitioners and researchers are encouraged to use the SI units. (Knuttgen, H. G., and Komi, and P. V.: Basic definitions for exercise. In Komi, P. V. (ed.): *Strength and Power in Sports.* Oxford, Blackwell Scientific Publications, 1992, pp. 3–6.

Units of Measure*

Distance

1 inch = 2.54 centimeters (cm) = 25.4 millimeters (mm) = 0.0254 meters (m)
1 foot = 30.84 cm = 304.8 mm = 0.3048 m
1 mile = 5280 (feet (ft) = 1760 yards (yd) = 1609.35 m = 1.61 kilometers (km)
1 meter = 39.37 inches (in) = 3.28 ft = 1.09 yd
1 km = 0.621 mile (mi)

Energy and Work

Work = energy = application of a force through a distance
1 kilocalorie (kcal) = amount of energy required to heat 1 kilogram (kg) of water 1 degree celsius (from 15 to 16° C)
Joule (J) = the SI unit for work and represents the application of a force of 1 Newton (N) through a distance of 1 m
Newton (N) = that force that will produce an acceleration of 1 m · sec^{-2} (m/sec/sec) in a mass of 1 kg, (1 kg wt = 9.80655 N) or 1 kg · m · sec^{-2}
1 foot pound (ft-lb) = distance through which 1 lb is moved 1 foot
1 kilogram meter (kg-m) = distance through which 1 kg is moved 1 meter
1 kcal = 3087 ft-lb = 426.85 kg-m = 4.186 kilojoules (kJ)
1 kJ = 1000 J = 0.23892 kcal
1 liter of O_2 consumed = 5.05 kcal = 21.137 kJ = 2153 kg-m = 15,575 ft-lb
1 ft-lb = 0.1383 kg-m = 1.3558 J = 0.00032389 kcal (3.2389 10^{-4})
1 kg-m = 7.233 ft-lb = 9.8066 J = 0.0023427 kcal (2.3427 10^{-4})

Power

Power = work divided by time; measured in horsepower (hp) and watts
1 hp = 33,000 ft-lb · min^{-1} = 4564 kg-m · min^{-1} = 745.7 watts (W) = 745.7 J · sec^{-1} 10.688 kcal · min^{-1}
1 watt (W) = 0.00134 hp = 6.118 kg-m · min^{-1} = 44.25 ft-lb · min^{-1} (50 W = 300 kpm · min^{-1})
1 ft-lb per minute (ft-lb · min^{-1}) = 0.1383 kg-m · min^{-1} = 0.00003 hp = 0.0226 W
1 kg-m · min^{-1} = 7.23 ft-lb · min^{-1} = 0.00022 hp = 0.1635 W
1 liter of O_2 consumed per minute = 5.05 kcal · min^{-1} (kcal/min) = 2153 kg-m · min^{-1} (kg-m/min) = 15,575 ft-lb · min^{-1} (ft-lb/min)
1 MET = 3.5 ml O_2 · kg^{-1} · min^{-1} (ml/kg/min) = 0.01768 kcal · kg^{-1} · min^{-1} (kcal/kg/min) = 0.07398 kJ · kg^{-1} · min^{-1} (kJ/kg/min)

Velocity

1 ft per second (ft · s^{-1}) = 0.3048 m · s^{-1} = 18.3 m · min^{-1} = 1.1 kilometer per hour (kph) = 0.68 miles per hour (mph)
1 mph = 88 ft · min^{-1} = 1.47 ft · s^{-1} = 0.45 m · s^{-1} = 26.8 m · min^{-1} = 1.61 kph
1 kph = 16.7 m · min^{-1} = 0.28 m · s^{-1} = 0.91 ft · s^{-1} = 0.62 mph

Weights

1 ounce (oz) = 0.0625 lb = 28.35 grams (g) = 0.029 kg
1 pound (lb) = 16 oz = 454 g = 0.454 kg
1 g = 0.035 oz = 2.205 lb = 0.001 kg
1 kg = 35.27 oz = 2.205 lb = 1000 g

Temperature

0° C (Centigrade) = 32° F (Fahrenheit) = 273° K (Kelvin)
100° C = 212° F

Pressure

1 Atmosphere = 760 mmHg (at 0° C) = 760 torr = 29.0213 inch Hg (at 32° F)

SI Units (Systeme International)*

Physical quantity	Unit	Symbol
Mass	kilogram	kg
Distance	meter	m
Time	second	sec
Amount of substance	mole	mol
Force	newton	N
Work	joule	J
Power	watt	W
Velocity	meters per sec	m · sec^{-1}
Torque	newton-meter	N-m
Angle	radian	rad
Angular Velocity	radians per second	rad · s^{-1}
Acceleration	meters per second^2	m · sec^{-2}
Volume	liter	L

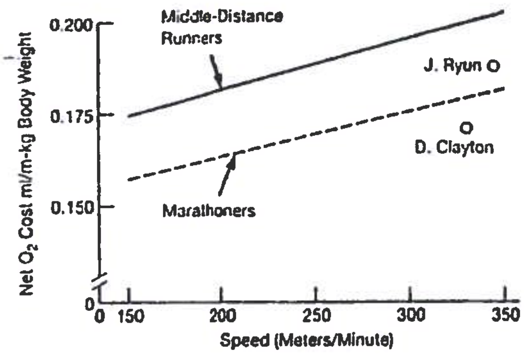

Figure 4.6. Differences in running efficiencies between middle-distance runners and marathon runners. Marathon runners are about 5 to 10% more efficient than middle-distance runners. The great miler J. Ryun is the most efficient of the middle-distance runners, and D. Clayton, the world's best marathoner, is the most efficient among the marathon runners. (Based on data from various sources as compiled by Fox and Costill.[10])

Efficiency is also different between middle-distance and marathon runners.[10] This is illustrated in Figure 4.6. Efficiency is represented by the net oxygen cost of running at various speeds and is expressed as ml of oxygen per horizontal meter (m) run and per kg of body weight (ml/m-kg). Remember, the higher the net oxygen cost, the lower the efficiency. Marathon runners are about 5 to 10% more efficient on the average than middle-distance runners. This advantage, though small for runs of short duration, would be an important consideration during the 2½ hours required to run a good marathon race. For example, a 10% greater efficiency would mean a "savings" of about 60 liters of oxygen consumed or 300 kcal of heat produced per marathon race! Also, note that the great half-mile and mile runner Jim Ryun was the most efficient of the middle-distance runners, and Derek Clayton was the most efficient among the marathon runners.

Factors Affecting Efficiency

Cavanagh and Kram have discussed factors that affect efficiency and economy of movement.[4] They identify structural factors and optimal phenomena. Structural factors include total body mass, distribution of body mass, variations in the distance of insertions of key muscles from joint centers, and variations in muscle fiber orientation and length.

Observations have been made on several types of human movement in which biomechanical variables have been manipulated. Such manipulations produce energy cost curves that have a point of least energy cost. Cavanagh and Kram characterized these points as *optimal phenomena*. Some activities in which optimal phenomena have been observed include:[4]

1. The energetics of riding a bicycle at a constant power output are affected by seat height.
2. Maximal power output is also affected by seat height.
3. Pedal frequency affects energy cost at a constant power output. A mean value of 91 rpm was "chosen" by competitive cyclists.
4. A self-selected stride length in running at a given speed affects energy cost.
5. Analysis of running and walking at various downhill grades shows a minimum energy cost at a −5% grade.
6. A speed of walking exists at which the energy required to walk a given distance is minimized.

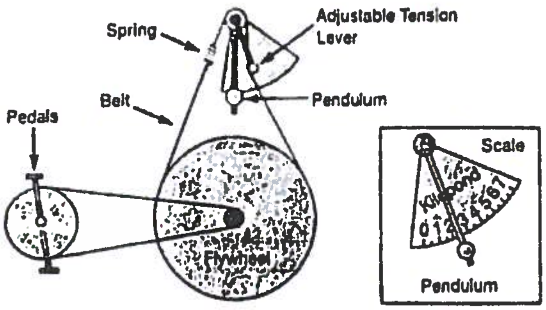

Figure 4.7. Components of a mechanically braked cycle ergometer. A weighted flywheel has a belt around its circumference. The belt is connected with a small spring on one end and has an adjustable tension lever on the other end. A pendulum balance indicates the resistance in kiloponds. The inset shows the pendulum at a resistance of 2 kiloponds.

Measuring Efficiency on a Cycle Ergometer

Figure 4.7 depicts a mechanically braked cycle. A belt runs around the rim of a flywheel and can be provided with greater tension through an adjustable dial.[25] By increasing tension on the wheel more friction, and thus greater resistance, is provided. The cycle gearing and wheel circumference have been designed so that one complete turn of the pedals moves a point on the rim 6 meters (the rim is 1.6 meters in circumference). With a metronome set at 100 counts per minute (50 rpm) a scale is provided that is graduated in *kiloponds* (*kp*). One kp is the force acting on the mass of 1 kg at the normal acceleration of gravity. The braking power, in kp, multiplied by the distance pedaled in meters yields work in *kilopond-meters* (*kp-m*). If the distance "traveled" is related to time, then power can be expressed as kp-m/min. Power can also be expressed as watts, kg-m/min, or joules/sec.

The relationship among the various work units *at 50 rpm* is: 1 kp = 300 kp-m (= 300 kg-m) = 723 ft-lb.* From Table 4.2 we see that the work units can be converted to energy units of kilocalories (kcal) or kilojoules (kJ).† 1 kcal = 3086 ft-lb/min = 426.78 kg-m/min = 4.186 kJ/min.

There are several newer cycle ergometers available for laboratories and personal usage that are electronically braked and compensate for variations in pedal frequency. That is, if the subject pedals at a faster rate, the resistance will be lowered so that the total work output will be constant. The mechanically braked cycle, described previously, represents an inexpensive, reliable research ergometer. For computing the efficiency, we need to know both the work accomplished (output) and the work (energy) expended (input) by the subject.

In the following example, a subject exercises for 10 minutes on a cycle ergometer at a resistance of 3 kp. The task is to determine efficiency for the 10 minutes.

1. *Work Output.* To determine work output, we need to know the resistance (3 kp), the total time (10 min), the pedaling rate (50 rpm), and the distance the rim of the flywheel travels (6 meters per revolution).

(a) Determine the work performed.

$W = F \times D$
$W = (3 \text{ kp}) \times (50 \text{ rpm} \times 10 \text{ min} \times 6 \text{ m per rev})$
$W = (3 \text{ kp}) \times (3000 \text{ m})$
$W = \mathbf{9000\ kp\text{-}m = 9000\ kg\text{-}m}$

(b) Convert to kilocalories.

1 kcal = 426.78 kg-m

Total kcal = 9000 kg-m / 426.78 kg-m/kcal
kcal = **21.09**

2. *Work Input.* To determine work input, we need to know the R-value (in order to acquire the caloric equivalent of a liter of oxygen) and the total oxygen consumed. Recall that R can be determined only under steady-state conditions, thus the work must be submaximal.

Given:

R = 0.85 (From Table 4.4, 1 liter of O_2 = 4.865 kcal)
$\dot{V}O_2$ = 2.0 L/min
Exercise time = 10 minutes

(c) Determine total oxygen consumed.

Total VO_2 = (2.0 L/min) × (10 min)
= **20 liters of oxygen**

(d) Total calories consumed = (20 L) × (4.865 kcal/liter)
= **97.3 kcal**

(e) $$\% \text{ EFF} = \frac{21.09 \text{ kcal}}{97.30 \text{ kcal}} \times 100 = \mathbf{21.7\%}$$

Many contemporary cycle ergometers are calibrated to give a direct readout in power units (i.e., watts or kilogram-meters per unit of time). Efficiency may still be computed as was previously mentioned, so long as the numerator and denominator are expressed in identical units (power or work).

Measuring Efficiency on a Treadmill

If the subject were walking or running horizontally on the treadmill, he or she would not be performing "useful" work and therefore efficiency could not be

---

*Note that this relationship changes with different pedal frequencies.

†Joule is the international unit for work. 1 kp = 9.80665 newtons (N). A Newton-meter is expressed in joules.