Instructor's Manual for *Nutrition for Sport & Exercise* 3e
Chapter 2 – Defining and Measuring Energy

Overarching Concepts

1. The energy contained in food is converted to chemical energy in the body and used immediately or stored for later use.
2. The caloric content of foods can be estimated but the precise amount of energy that food yields in the human body is not known.
3. Energy expenditure can be measured, but not easily. An open-circuit metabolic measurement system found in most exercise physiology labs is a reasonably practical and accurate measurement technique.
4. Resting metabolic rate (RMR) can be measured with reasonable accuracy. Most of the influences on RMR are not under voluntary control or are subtle. Increasing skeletal muscle via resistance exercise is a practical and effective way to increase RMR.
5. Caloric intake, RMR, thermic effect of food (TEF), and energy expenditure through physical activity can be reasonably estimated. These estimates can be used to determine "energy in" and "energy out" and to predict whether energy balance or imbalance is likely.

Learning Objectives

LO 2.1 Define and explain bioenergetics (using in your definition ATP, calorie, kilocalorie, and other energy-related terms), explain the concepts of energy transfer and utilization in the body, and identify the primary source of energy in the body and how it is used by skeletal muscle during exercise.

LO 2.2 Explain how the energy content of food and energy expenditure are measured directly and indirectly and how the most accurate estimates can be made.

LO 2.3 List and explain the components of the energy balance equation, the factors that influence metabolic rate, how metabolic rate is measured or predicted, and the impact of physical activity on energy expenditure.

Chapter Outline

I. Introduction
   A. Pre-test assessment
   B. Introductory concepts
      1. Energy is a huge topic
      2. Understanding how to define and measure energy is a good starting point
      3. Energy balance is simply defined as "Energy in = Energy out"

II. 2.1 Energy and energy concepts
   - Energy contained in food is transferred to other forms that can be used in the body.
   - High-energy phosphates such as adenosine triphosphate (ATP) are chemicals that can store and release energy.
   - ATP is the common energy source used by all cells in the body.
   - Energy for muscle contraction is provided directly by ATP.
   - Three major energy systems are used to replace ATP that is used for muscle contraction.

   A. Energy is the ability to perform work.
      1. Definition: Energy is the ability to do work
      2. Energy exists in different forms
         a. Chemical work (e.g. stored carbohydrate or fat for later use)

    b. Electrical work (e.g. transmission of neurological impulses)
    c. Mechanical work (e.g. force production by skeletal muscle)
    d. Transportation work (delivery of oxygen and nutrients to tissues)
3. First Law of Thermodynamics
    a. “Within in a closed system, energy is neither created or destroyed”
    b. Humans are relatively inefficient “machines”
4. Storing and releasing energy
    a. Potential energy
        1. Stored energy (e.g. water behind a dam, muscle glycogen)
    b. Kinetic energy
        1. Energy of motion (e.g. release of water from a dam, use of glycogen during exercise)
    c. Endergonic reactions
        1. Processes or reactions that store energy
        2. Examples: setting a mousetrap, rephosphorylation of ADP to form ATP
    d. Exergonic reactions
        1. Processes or reactions that release energy
        2. Examples: springing of a mousetrap, release of energy when ATP is hydrolyzed

B. High-energy phosphate compounds store and release energy.
1. Adenosine triphosphate (ATP)
    a. Structure
    b. Breakdown of ATP and the release of energy
    c. Spotlight on… The Role of Enzymes
2. Use of ATP by muscle
    a. Attachment (crossbridges)
        1. Energy from ATP puts myosin heads in an energized state
    b. Force production (contraction)
        1. Power stroke
        2. Sliding Filament Theory
    c. Detachment (relaxation)
        1. Reloading of ATP on the myosin head
    d. ATP concentration in muscle
        1. Does not drop more than 20-30%
        2. Muscle fatigues and protects against ATP depletion
3. Resynthesis of ATP
    a. ADP is rephosphorylated to form ATP
    b. Three energy systems to replenish ATP
        1. Creatine phosphate
        2. Anaerobic glycolysis
        3. Oxidative phosphorylation

Question for discussion: What happens when ATP levels in muscle decrease too much?

III. 2.2 Measuring Energy

- The SI unit of measure for energy is the Joule (J).
- Because the amount of energy expressed by a Joule is small, the kilojoule (kJ) is commonly used when expressing the energy contained in food. In countries such as the United States, energy in food is expressed as kilocalories (kcal), with 1 kcal being equal to 4.2 kJ.
- The energy content of foods is determined by direct calorimetry in which the heat energy released is measured when they are burned in a bomb calorimeter.

- The energy content of carbohydrates, fats, proteins, and alcohol is expressed as the number of kilocalories per gram of that food, and is approximately 4, 9, 4, and 7 kcal/g, respectively.
- Energy expenditure by individuals can be measured by direct calorimetry in room-size calorimeters or by indirect calorimetry by measuring the amount of oxygen consumed and carbon dioxide produced.

A. Introductory concepts
   1. International System of Units (SI units)
   2. Joule (J)
   3. Correct terminology: Calorie (C) or kilocalorie (kcal) or kilojoule (kJ)
   4. Commonly used in the U.S.: calorie (cal)
   5. To convert kJ to kcal: divide kJ by 4.2 kcal/kJ
      a. 8,400 kJ ÷ 4.2 kcal/kJ = 2,000 kcal

B. The energy content of food is measured by calorimetry.
   1. Direct calorimetry
      a. Bomb calorimeter measures temperature change when food is burned
   2. Caloric content of carbohydrates, fats, proteins, and alcohol
      a. Bomb calorimeter vs. human calorimeter
         1. Humans cannot completely burn protein
         2. Carbohydrates
            a. 4.2 kcal/g (rounded to 4 kcal/g)
         3. Proteins
            a. 5.7 kcal/g in bomb calorimeter
            b. Nitrogen cannot be oxidized by humans
            c. 4.2 kcal/g (rounded to 4 kcal/g)
         4. Fats
            a. 9.4 kcal/g (rounded to 9 kcal/g)
         5. Alcohol
            a. 7.0 kcal/g (slightly less if liver cells are damaged)
         6. "Rule of thumb" calculations
            a. 10 g carbohydrate or protein = 40 kcal
            b. 10 g fat = 90 kcal
            c. 10 g alcohol (ethanol) = 70 kcal
         7. All caloric values for humans are only estimates
            a. Strict "calorie counting" not recommended

C. The amount of energy expended can be measured directly or indirectly.
   1. Direct calorimetry
      a. Measures temperature change by measuring heat associated with energy expenditure
      b. Whole-room calorimeters are used for research
   2. Indirect calorimetry
      a. Measures relationship between oxygen consumption, carbon dioxide production, and energy expenditure
      b. Whole-room calorimeters are used for research
      c. Open-circuit metabolic measurement systems
         1. 1 liter (1 L) oxygen consumed = approximately 5 kcal of energy expenditure
         2. Figure includes energy used for resting metabolism
         3. Resting metabolic rate (RMR) can be calculated separately
         4. Used in exercise physiology labs (AND in specialized practice; e.g., exercise physiology professionals who take measurements in the athletes' usual work environments)
      d. Portable systems
         1. Measuring RMR
            a. Guidelines for more accurate measurement

            1. Fast for at least 5 hr
            2. Abstain from alcohol or nicotine for at least 2 hr
            3. Abstain from caffeine for at least 4 hr
            4. Abstain from vigorous resistance exercise for at least 14 hr
            5. Abstain from moderate exercise for at least 2 hr
         b. Used in nonresearch settings such as health clubs
      2. Estimating energy expenditure
         a. Used for research
   e. Long-term measurements
      1. Doubly Labeled Water (DLW)
         a. Used for research
   f. Accuracy - Focus on Research highlight

Questions for discussion: (1) What type of energy expenditure measurement device would be best suited to obtaining accurate measurements while an athlete is performing in his or her sport (for example, playing soccer)? (2) What is meant by the statement, "Food = fuel = exercise?"

IV. 2.3 Concepts of energy balance

- Energy intake is determined by recording and analyzing food intake, which must be done accurately for the results to be meaningful.
- The major influences on energy expenditure are resting metabolism and physical activity.
- Resting metabolism accounts for approximately 70 percent of a sedentary person's daily energy expenditure and can be influenced by a variety of factors. The two major factors under voluntary control are avoiding a starvation diet and building and maintaining skeletal muscle mass.
- Resting metabolic rate and total energy expenditure can be measured by direct or indirect calorimetry, and/or estimated by using prediction equations.
- The factor contributing to daily energy expenditure that can be influenced the most by voluntary behavior is physical activity.
- Energy balance refers to the relationship between the amount of energy consumed and the amount of energy expended, usually on a daily (24-hour) basis.
- Athletes should first consider their energy expenditure and then plan their energy intake to meet the demands and goals of their training and competition.

A. "Energy in = energy out"
B. Energy intake is estimated by analyzing daily food and beverage consumption.
   1. Self-reported food intake
      a. Accurate recording is needed
      b. Portion sizes must be estimated correctly
      c. Food intake is typically underestimated by 10-20%
      d. Errors in data entry can occur
C. Components of energy expenditure can be estimated by different methods.
   1. Total Energy Expenditure (TEE)
      a. Resting metabolism
      b. Thermic effect of food
      c. Physical activity
   2. Basal and resting metabolism
      a. The major component of TDEE
      b. Basal metabolic rate (BMR)
         1. Minimal amount of energy needed to sustain life
         2. Measured under defined laboratory conditions
         3. Used for research

        c. Resting metabolic rate (RMR)
            1. Estimate of BMR
            2. Measured under less strict conditions
            3. RMR is typically 10% greater than BMR
            4. Used for practical purposes
            5. Approximately 70% of TEE is attributed to RMR
            6. Factors affecting RMR
                a. Not under voluntary control
                    1. Gender
                        a. RMR slightly less for females
                    2. Genetics
                        a. RMR tends to be similar among family members
                    3. Age
                        a. RMR decreases with age
                        b. Approximately 1-2% decrease per decade
                    4. Height
                        a. Larger body surface area = higher RMR
                    5. Thyroid hormones
                b. Substantial influence, under some voluntary control
                    1. Starvation
                        a. Decreases RMR by 20% or more
                        b. Too severe of a caloric restriction impedes weight loss
                        c. RMR does not return to baseline immediately after re-feeding
                    2. Amount of fat-free mass
                        a. Increases RMR because fat-free tissue is more metabolically active than fat
                        b. Resistance exercise can increase fat-free tissue
                c. Subtle influence, under some voluntary control
                    1. Exercise
                        a. Study results are inconsistent
                        b. Consensus opinion: RMR increased for short period of time (10-90 minutes)
                    2. Environmental temperature/altitude
                        a. Increased RMR if colder or higher altitude
                        b. Increase is temporary
                    3. Caffeine
                        a. RMR increased for short period of time (approximately 2-3 hrs)
    3. Estimating resting metabolic rate (RMR)
        a. For practical reasons, typically estimated via prediction equations
        b. Prediction equations are only estimates
            1. Mifflin-St. Jeor is reasonably accurate to use with nonobese and obese healthy Caucasians (excellent step-by-step instructions in Figure 2.23)
            2. Cunningham equation better accounts for fat-free mass and may be more accurate to use with athletes
            3. A very simple formula is used when no other method is available
    4. Thermic Effect of Food (TEF)
        a. Energy required for the digestion and absorption of food
        b. Estimated to be 10% of total caloric intake for the day
        c. Proteins increase TEF more than carbohydrates
        d. Effect of TEF on RMR is very small
    5. Physical activity
        a. Under substantial voluntary control
        b. Can be a substantial influence on TEE
    6. Estimating daily energy expenditure through physical activity
        a. Self-reported activity logs are the most practical method

7. Estimating energy expended by a single physical activity
    a. Use of computer program is easy and practical
    b. Hand calculations are also possible
    c. Estimates typically include RMR as well as energy expended from the activity
D. Estimated Energy Requirement is a daily balance of energy intake and expenditure.
    1. Estimated energy requirement (EER)
    2. Use of computer program is easy and practical
    3. A “ballpark” figure is used when no other method is available
        a. “Ballpark” figures based on gender and physical activity level
            1. Range: 30 kcal to 58 kcal/kg/day
            2. Estimates derived from surveys and clinical observations

Question for discussion: What are the advantages and disadvantages of the various methods for estimating energy expenditure for physical activities such as walking or jogging?

V. Summary and review
    A. Chapter summary
    B. Post-test assessment
    C. Review questions
    D. References

Supplementary Teaching Materials and Classroom Activities

Note: The text chapter includes an application exercise requiring determination of RMR and exercise-related energy expenditure (p. 60).

Activity 2-1
Arrange for students to observe or participate in indirect calorimetry of energy expenditure in an on-campus exercise physiology laboratory by contacting the lab early in the semester. Most exercise phys labs have an open-circuit metabolic measurement system that can be demonstrated to students. Other indirect calorimetry methods for determining energy expenditure may also be available. Students may be allowed to sign up for such measurements, although a fee may be required.

Similarly, a determination of resting metabolic rate (RMR) may be available to students. If demonstrated, have students calculate estimated RMR using the simplified formula (see Figure 2.25 on page 57). When the measurement RMR estimate is available have students compare the two estimates and discuss the magnitude of and reasons for the difference.

Activity 2-2
Have students practice energy calculations and conversions. This can be an in-class exercise or an out-of-class assignment. Some sample calculation questions are shown here (answers follow).

<u>In-Class Assignment</u>
Please show your work on calculations so that if you make a mistake you will be able to see where the mistake was made.

1. On average, male jockeys consume approximately 6769 kJ daily. How many kcal are consumed?
2. Female jockeys consume approximately 1,480 kcal daily. How many kJ are consumed?
3. How many kcal in 1 teaspoon of oil?
4. How many kcal in a 12 oz. Budweiser beer?

5. If a food contains 35 g carbohydrate, 4 g protein, and 14 g fat, how many kcal are there? How many kJ are in this food?
6. Determine your body weight in kg. If you do not wish to use your own weight, calculate the body weight in kg of someone who weights 176 lb.

<u>In-Class Assignment Answers</u>

1. On average, male jockeys consume approximately 6769 kJ daily. How many kcal are consumed?

   6769 kJ ÷ 4.2 kcal/kJ = 1,612 kcal

2. Female jockeys consume approximately 1,480 kcal daily. How many kJ are consumed?

   1,480 kcal × 4.2 kJ/kcal = 6,216 kJ

3. How many kcal in 1 teaspoon of oil?

   Before performing this calculation students will need to know that 1 teaspoon of oil contains 5 g. Not including this information in the original question makes students think about what information they need to solve this problem.

   5 g × 9 kcal/g = 45 kcal

4. How many kcal in a 12 oz. Budweiser beer?

   Students will need to know that this beer contains 11 g of carbohydrate (CHO) and 14 g of alcohol.

   11 g CHO × 4 kcal/g = 44 kcal of CHO
   14 g alcohol × 7 kcal/g = 98 kcal of alcohol
   44 kcal + 98 kcal = 142 kcal

5. If a food contains 35 g carbohydrate, 4 g protein, and 14 g fat, how many kcal are there? How many kJ are in this food?

   35 g CHO × 4 kcal/g = 140 kcal of CHO
   4 g protein × 4 kcal/g = 16 kcal of protein
   14 g fat × 9 kcal/g = 126 kcal of fat
   140 kcal + 16 kcal + 126 kcal = 282 kcal

   282 kcal × 4.2 kJ/kcal = 1,184 kJ

   Ask students to guess what food this might be. (Snickers Bar)

6. Determine your body weight in kg. If you do not wish to use your own weight, calculate the body weight in kg of someone who weights 176 lb.

   176 lb ÷ 2.2 lb/kg = 80 kg

Activity 2-3

Have students estimate daily energy expenditure. This can be an in-class exercise or an out-of-class assignment. Some sample calculation questions and answers are shown here.

<u>In-Class Assignment</u>

1. Estimate your daily energy expenditure using the sedentary activity level figure in Table 2.4 (see page 62). If you do not wish to use your own weight, make the calculation based on someone who weights 142 lb.

   The estimate is based on 30 kcal/kg for females and 31 kcal/kg for males.

   142 lb (64.5 kg) female:
   64.5 kg × 30 kcal/kg = 1,935 kcal

142 lb (64.5 kg) male:
64.5 kg × 31 kcal/kg = 2,000 kcal

2. Using Table 2.4, estimate your daily energy expenditure for the three periods—preparation, competition, and transition ("off-season")—previously outlined when you sketched a general training plan (see chapter 1 activities).

   142 lb (64.5 kg) male:

   Preparation (training 3-5 days/week): 38 kcal/kg
   Competition (training 5 days/week): 41 kcal/kg
   Transition (sedentary): 31 kcal/kg

   64.5 kg × 38 kcal/kg = 2,451 kcal
   64.5 kg × 41 kcal/kg = 2,644 kcal
   64.5 kg × 31 kcal/kg = 1,999 kcal

   For most athletes, energy expenditure is lowest in the transition period (active recovery or "off season").

<u>Outside of Class Assignment</u>
Record all of your activities for one or more days. Using the *Diet Analysis+* computer program that accompanies this textbook, enter in all activities for each 24-hour period. These activities will include activities of daily living such as sleeping, sitting, and working at a desk job as well as specific physical activities. You must enter in activities for a total of 24 hours. An estimate of 24-hour energy expenditure can be viewed on the screen or printed.

If you are recording more than one day's activities, it is recommended that you choose at least one day that you consider to be active and one day that is relatively sedentary. If you are in training, record current activity, but you may also want to estimate energy expenditure in another mesocycle for comparison purposes.

After you have an estimate of 24-hour energy expenditure, an analysis can be made by comparing high and low energy expenditure activities (e.g. sitting for 1 hour vs. physical activity for 1 hour). If data are available, day-to-day variations or estimated energy expenditure for the different mesocycles can also be compared. If you have estimated energy expenditure using Table 2.4, comparisons can be made between the two methods.

Crossword Puzzle Answer Key[1]
1. rephosphorylation
2. ATP
3. reliability
4. bioenergetics
5. calorimeter
6. doubly labeled water
7. kilocalorie
8. joule
9. calorie
10. validity
11. adipose tissue
12. TEE

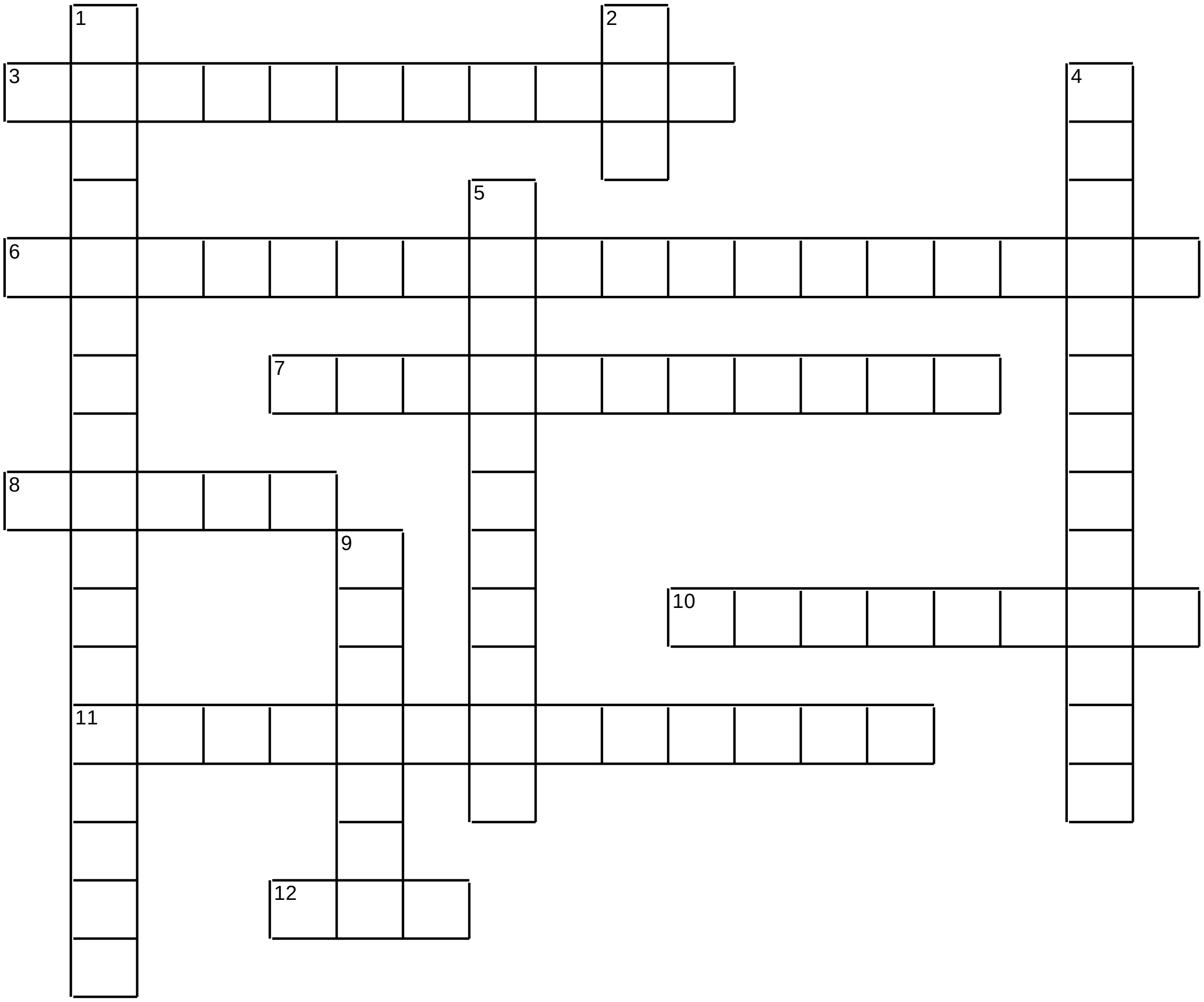
Word Find Puzzle Answer Key
- 6 forms in which energy exists: atomic, chemical, electrical, mechanical, radiant, thermal
- 2 units used to express energy measurements: joule, calorie
- 4 food components that yield energy: carbohydrate, fat, protein, alcohol

[1] Crossword and word find contributed by Elesha Feldman

- 2 substances measured in indirect calorimetry: oxygen, carbon dioxide
- 2 isotopes measured in doubly labeled water: oxygen-eighteen, deuterium
- 3 major components of TEE: metabolism, thermic effect of food, physical activity
- 3 non-modifiable factors that influence RMR: age, gender, genetics

A	T	O	M	I	C	P	W	G	E	N	E	T	I	C	S	H	E	N
L	T	H	E	Y	T	H	A	P	O	U	R	M	O	A	N	D	A	Y
C	A	R	B	O	H	Y	D	R	A	T	E	H	E	L	A	D	S	J
O	T	W	A	O	Z	S	O	M	B	H	I	E	G	O	S	W	O	E
H	F	W	A	D	L	I	K	I	D	E	U	T	E	R	I	U	M	D
O	N	A	O	U	I	C	R	S	T	R	E	E	N	I	L	A	E	I
L	M	D	T	C	T	A	H	I	S	M	T	L	D	E	O	W	T	X
N	E	S	E	H	E	L	N	M	S	A	H	E	E	A	R	D	A	O
L	C	Y	W	E	O	A	I	T	R	L	T	C	R	H	O	U	B	I
T	H	E	R	M	I	C	E	F	F	E	C	T	O	F	F	O	O	D
R	A	T	I	I	M	T	T	E	O	A	N	R	D	W	E	L	L	N
L	N	N	O	C	L	I	O	O	X	N	G	I	E	R	M	E	I	O
E	I	M	O	A	R	V	R	I	Y	Z	E	C	O	R	G	R	S	B
H	C	Y	M	L	E	I	P	T	G	O	O	A	F	A	A	R	M	R
A	A	L	O	N	G	T	I	N	E	O	U	L	R	C	R	I	M	A
E	L	S	T	O	X	Y	G	E	N	E	I	G	H	T	E	E	N	C

Chapter 2 Crossword Puzzle



Across	**Down**
3. Ability to reproduce a measurement and/or the consistency of repeated measurements. 6. A measurement technique for determining energy expenditure over a long time period using radioactively labeled hydrogen and oxygen. 7. The amount of heat energy required to raise the temperature of 1 kilogram of water 1°C. 8. The work done by a force of 1 Newton acting to move an object 1 meter. 10. Ability to measure accurately what was intended to be measured. 11. Tissue made up of fat cells. 12. The amount of energy that is required by the body, typically determined over the course of a 24-hour day.	1. Reestablishing a chemical phosphate bond (e.g., ADP to ATP). 2. A chemical compound that provides most of the energy to cells. 4. The process of converting food into biologically useful forms of energy. 5. A device that measures energy content of food or energy expenditure. 9. The amount of heat energy required to raise the temperature of 1 gram of water by 1°C.

Chapter 2 Word Find Puzzle

A	T	O	M	I	C	P	W	G	E	N	E	T	I	C	S	H	E	N
L	T	H	E	Y	T	H	A	P	O	U	R	M	O	A	N	D	A	Y
C	A	R	B	O	H	Y	D	R	A	T	E	H	E	L	A	D	S	J
O	T	W	A	O	Z	S	O	M	B	H	I	E	G	O	S	W	O	E
H	F	W	A	D	L	I	K	I	D	E	U	T	E	R	I	U	M	D
O	N	A	O	U	I	C	R	S	T	R	E	E	N	I	L	A	E	I
L	M	D	T	C	T	A	H	I	S	M	T	L	D	E	O	W	T	X
N	E	S	E	H	E	L	N	M	S	A	H	E	E	A	R	D	A	O
L	C	Y	W	E	O	A	I	T	R	L	T	C	R	H	O	U	B	I
T	H	E	R	M	I	C	E	F	F	E	C	T	O	F	F	O	O	D
R	A	T	I	I	M	T	T	E	O	A	N	R	D	W	E	L	L	N
L	N	N	O	C	L	I	O	O	X	N	G	I	E	R	M	E	I	O
E	I	M	O	A	R	V	R	I	Y	Z	E	C	O	R	G	R	S	B
H	C	Y	M	L	E	I	P	T	G	O	O	A	F	A	A	R	M	R
A	A	L	O	N	G	T	I	N	E	O	U	L	R	C	R	I	M	A
E	L	S	T	O	X	Y	G	E	N	E	I	G	H	T	E	E	N	C

Instructions: In the grid above, find the following words or phrases, and then write them beside each clue.

- 6 forms in which energy exists:
- 2 units used to express energy measurements:
- 4 food components that yield energy:
- 2 substances measured in indirect calorimetry:
- 2 isotopes measured in doubly labeled water:
- 3 major components of TEE:
- 3 non-modifiable factors that influence RMR: