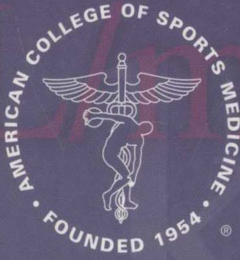

AMERICAN COLLEGE of SPORTS MEDICINE®
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ACSM's Metabolic Calculations HANDBOOK

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PREFACE

There is both an art and a science to exercise prescription. Individual differences require that exercise professionals be able to create specific, individualized programs for their clients. While mode, duration, and frequency are often easily chosen and adjusted, exercise intensity is something that requires specific tools to accurately quantify. The metabolic equations are valuable tools to assist the exercise professional in quantifying exercise intensity and caloric expenditure. They are also very helpful when setting the exercise intensity goal for the client. The ability to provide exercise intensity information that relates to specific measurements from a graded exercise test or some other functional capacity guideline means that clients can exercise in a safer and more prudent intensity range.

This text is designed for the exercise professional who may work in clinical as well as health-fitness settings. It is also designed for the instructor of a course in exercise physiology or exercise testing and prescription who is teaching the use of these equations. In the clinical setting, training intensity is often a very narrow range, and exceeding prescribed intensity can lead to adverse signs and symptoms. Data from an exercise test, in concert with the metabolic equations, can be used to set the proper training intensity. In many rehabilitation settings, exercise mode is often rotated to allow for a wider range of training adaptations. The metabolic equations are very helpful in setting appropriate work rates across modes. Similarly, in the health and fitness settings, exercise prescriptions are often based upon exercise test data, and the metabolic equations will be essential to help define the appropriate exercise intensity. For home-based exercise programs, speed and time can be measured from walking or running, and oxygen cost and caloric expenditure can be measured. For individuals tracking energy expenditure (i.e., weight loss program), the equations will help them determine their energy expenditure.

This text will also be useful for individuals working within rehabilitation settings where their primary goal may be injury rehabilitation. Often during rehabilitation from an injury, the clinician is also involved with training the whole person. For example, weight loss may alleviate some orthopedic pain symptoms, so the rehabilitation specialist may employ an exercise program. In summary, anyone who needs to set appropriate exercise intensity, or quantify the intensity that someone is already using, then this text is for you.

The metabolic equations provide oxygen consumption and work rate information, depending on how you complete them. Therefore the initial chapters cover the basics of metabolism and energy, explaining how oxygen can be used to determine caloric cost of an activity. The equations themselves use basic algebraic principles, and therefore a primer on basic algebraic is also included. The subsequent chapters are devoted to a step-by-step approach to understanding the equations. The equations can be used two ways: you can use work information (i.e., speed, grade, work rate, step rate) and calculate $\dot{V}O_2$, or if you know the desired $\dot{V}O_2$ for training you can calculate the appropriate work. We refer to this as working the equations forward or backward, and again the calculations are basic algebraic transformations.

Chapters 5–9 address each of the metabolic equations separately. The chapters begin with a basic introduction to the derivation of the equation, and provide examples of the various ways the equation can be used. Each chapter has a practice table with work intensity information missing. We anticipate this being a useful tool for the student and instructor in that the problem sets have been designed so that the student must work the equation both forward and backward in order to fill in the table. Following the table the answers are given as well as the step by step solutions. While there may be different approaches to solving the equations, we feel we have chosen the most straightforward for the non-mathmatically inclined. Chapter 10 is a summary chapter in which a set of problems are provided using all of the equations, solving both forward and backward. Step-by-step solutions to each is given. Chapter 11 is a test with only the solutions provided. The appendix provides a "cheat sheet" of sorts, which the student might use in class to assist with solving the problems. All of the equations as well as common conversions are given.

Our hope is that by going through the chapters, working the problems sets and following along with the step-by-step solutions, the student or professional will develop a strong familiarity with the practical uses of the metabolic equations.

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1

INTRODUCTION

The importance of physical activity and/or exercise has been clearly demonstrated in numerous scientific reports and announcements for improving overall health and physical fitness. While it is universally agreed that physical activity is important for health, the amount of physical activity necessary to attain these health benefits has been debated. A more exacting exercise prescription or program from a health/fitness professional may be possible and even more desirable for many clients when they attempt to increase their physical activity. Health/fitness professionals may need to be able to calculate, by measuring or estimating, the energy requirements of various forms of physical activity to best advise their clients and to individualize the amount and type of physical activity needed to improve and maintain their client's health.

Energy requirements can be expressed in terms of the oxygen requirements of the physical activity being performed—commonly referred to as the oxygen consumption or oxygen cost ($\dot{V}O_2$). $\dot{V}O_2$ is perhaps best known as a maximal measure ($\dot{V}O_{2max}$) and provides useful information for health/fitness professionals of their client's cardiorespiratory fitness (CRF). However, under steady-state exercise conditions, $\dot{V}O_2$ provides a measure of the energy cost of physical activity, frequently expressed in kilocalories (kcals) and in combination with carbon dioxide production ($\dot{V}CO_2$) provides information about the *relative mixture* of metabolic substrates or fuel sources (carbohydrate versus fat; more about this in Chapter 2, Metabolic Primer) utilized.

Measured oxygen consumption ($\dot{V}O_2$), using open-circuit spirometry, provides the health/fitness professional with the best measure of the energy cost of physical activity. However, $\dot{V}O_2$ measurement may not be practical for nonclinical purposes as it is arduous and costly (this is covered in more detail in Chapter 2).

Therefore, the estimation of the energy requirements of physical activity is desirable. A popular method for the estimation of the energy requirements of physical activity employs the American College of Sports Medicine's (ACSM) Metabolic Calculations (ACSM MetCalc). The ACSM first introduced the ACSM MetCalc in 1975 to provide health/fitness professionals with a practical method to estimate the oxygen cost of common physical activities (walking, running, leg cycling, arm cycling, and stepping). The use of the ACSM MetCalc involves using basic algebraic principles (i.e., solving for the unknown), which has been the source of confusion for many aspiring health/fitness professionals in the past; hence the need for this written text. It should be noted that this written text follows the *ACSM's Guidelines for Exercise Testing and Prescription*, seventh edition, as well as the CD-ROM, *ACSM's Metabolic Calculations Tutorial*, version 1.0A.

Calculating the appropriate exercise workload needed to elicit the desired oxygen consumption or energy cost will allow the health/fitness professional to develop a more effective and individualized physical activity and/or exercise program for their client.

To sum up the need for the ACSM MetCalc, Table 1.1 presents a list of the reasons for this algebraic solution to the energy requirements for physical activity:

TABLE 1.1 **Applications of the American College of Sports Medicine's Metabolic Calculations**

- Oxygen cost ($\dot{V}O_2$) for several forms of physical activity can be estimated.
- Oxygen cost ($\dot{V}O_2$) can be easily transferred into energy cost (kcals).
- Estimating the rate of oxygen cost during physical activity allows for an estimate of the energy expenditure and hence caloric consumption associated with the activity.
- Exercise prescription and programming can be individualized to meet a client's needs and goals. Physical activity programs can be individualized for a client based upon their goals and needs and precise estimates for workloads (e.g., speed, grade, etc.) can be provided to achieve a certain level of metabolic stress.

2

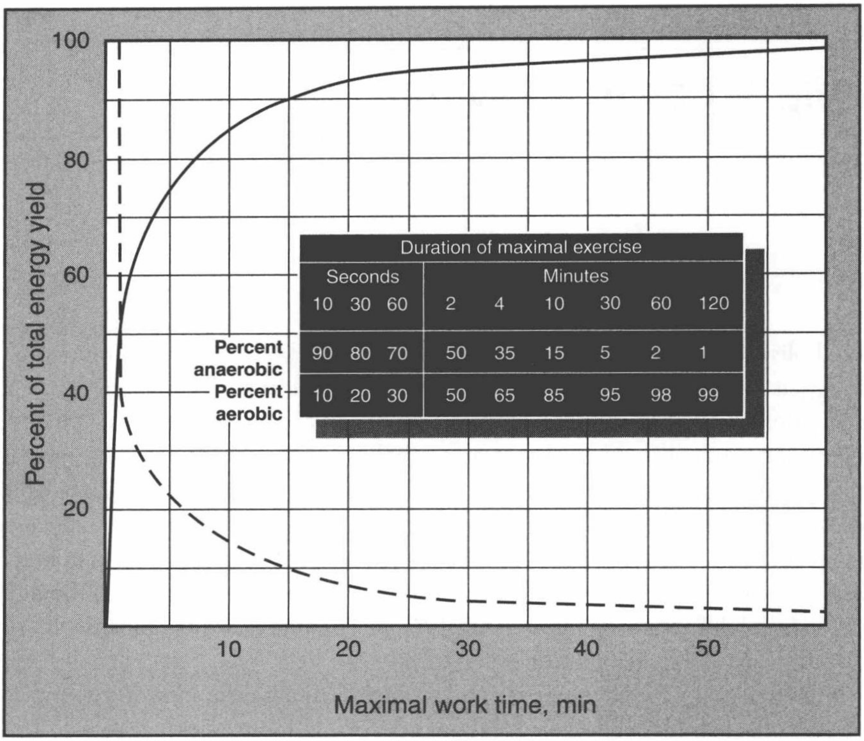
METABOLIC PRIMER

Metabolism is the sum of all energy processes in the body, both the production of energy, as well as the use of energy. Thus, metabolism is all about energy: use and production. The use or breakdown of energy is a catabolic process while the buildup or production of energy is an anabolic process. Exercise and/or physical activity is associated with energy use, while nutrition deals with energy availability and storage. Energy usage can be expressed in terms of oxygen usage since the long term usage of energy in humans involves oxygen. The use of oxygen in metabolism is known as *aerobic metabolism* while the use of energy without the aid of oxygen is, by definition, *anaerobic metabolism*. The terms aerobic means with oxygen while anaerobic means without oxygen.

Metabolism is a function of time and intensity. Metabolism is a continuum from anaerobic to aerobic while anaerobic metabolism is more closely associated with quick, short-term, more intense activities that last up to about 1–2 minutes and aerobic metabolism is more likely to be utilized during activities that last more than 4 minutes and are typically lower in intensity. Thus, aerobic metabolism is more long term and involves the use of oxygen. Figure 2.1 below expresses the continuum of metabolism. Oxygen usage can be measured by using sophisticated methodology or can be estimated (given certain pre-conditions as discussed in the next chapter) with the use of the American College of Sports Medicine's Metabolic Calculations (ACSM MetCalcs).

CATABOLISM BASICS

Adenosine triphosphate (ATP) is the energy currency in the human body. Most of energy usage (from muscle contraction through digestion) involves the use of ATP. ATP can be produced in three ways: (1) from the storage depots of creatine phosphate and ATP; (2) from anaerobic glycolysis; and (3) from aerobic glycolysis. Creatine phosphate (CP) is easily converted to ATP in the skeletal muscle and represents an immediate form of energy directly in the active muscles that may last up to 30 seconds. This conversion of CP to ATP is known as the immediate energy



Duration of maximal exercise

	Seconds			Minutes					
	10	30	60	2	4	10	30	60	120
Percent anaerobic	90	80	70	50	35	15	5	2	1
Percent aerobic	10	20	30	50	65	85	95	98	99

FIGURE 2.1 The Continuum of Metabolism. (Adapted with permission from McCardle WD, et al. *Essentials of Exercise Physiology* (2nd ed.). Philadelphia: Lippincott Williams & Wilkins, 2000.)

system and is anaerobic. However, the restoration of the CP and ATP stored in the muscle is aerobic.

Glycolysis is the conversion of glucose (or other simple carbohydrates) into ATP. Glycolysis may be either (1) anaerobic or (2) aerobic. Anaerobic glycolysis is a fast energy system that may last up to 2 minutes, does not involve oxygen in the energy pathway, and results in the production of the "end-product" lactic acid (that "tires" muscles). Aerobic metabolism is more complicated in its pathways (carbohydrate, fat, and amino acids may all participate as fuels) and may start from 2–4 minutes and continue indefinitely. Aerobic metabolism involves the use of oxygen.

During aerobic metabolism, either carbohydrate or fats are the major fuel substrates (amino acids from proteins are not utilized to a great extent). Aerobic metabolism is a slower energy system (therefore not able to produce ATP as quickly as is anaerobic glycolysis) but it is more complete in that the metabolic "leftovers," or end-products, of this pathway are carbon dioxide and water. Thus, aerobic metabolism consumes or uses oxygen and produces carbon dioxide.

EXPRESSIONS OF ENERGY USE

All actions in the human body require or use energy, from the digestion of foodstuff to muscle contraction. When we speak of exercise metabolism, we are often discussing the use of energy, known as energy expenditure. Energy expenditure in humans can be expressed several ways. Converting from one expression to another is relatively simple. To better understand energy expenditure you should be familiar with the following terms:

- **Aerobic metabolism:** production of energy using oxygen.
- **Oxygen consumption ($\dot{V}O_2$):** expression of the amount of oxygen used or consumed (typically as a rate or per minute).
- **Absolute versus relative:** relative, an expression relating the sum to some other value (such as body weight); while absolute, the expression of the value by itself.

Absolute Oxygen Consumption ($\dot{V}O_2$)

This is the volume of oxygen consumed by the person per unit (minute) of time, expressed in liters per minute ($L \cdot min^{-1}$) or milliliters per minute ($mL \cdot min^{-1}$). Resting absolute oxygen consumption ($\dot{V}O_{2rest}$) for a 70 kg person is approximately $0.25\ L \cdot min^{-1}$. In highly trained individuals, maximal absolute oxygen consumption ($\dot{V}O_{2max}$) can be as high as $5.0\ L \cdot min^{-1}$.

Absolute oxygen consumption is useful because it allows for an easy estimation of caloric expenditure. Each liter of O_2 consumed by the individual is associated with an energy expenditure of approximately 5 kilocalories (5 kcal). This will be discussed further in a later section.

Relative Oxygen Consumption ($\dot{V}O_2$)

This is the oxygen consumption relative to body weight, expressed in $mL \cdot kg^{-1} \cdot min^{-1}$; in other words, the volume of oxygen consumed by the cells of each kilogram of body weight every minute. The resting relative oxygen consumption ($\dot{V}O_{2rest}$) is approximately $3.5\ mL \cdot kg^{-1} \cdot min^{-1}$. In highly trained aerobic athletes, a maximal relative oxygen consumption ($\dot{V}O_{2max}$) can be as high as $80.0\ mL \cdot kg^{-1} \cdot min^{-1}$ (Figure 2.2).

In some instances, $\dot{V}O_2$ is expressed relative to a kilogram of fat-free mass, or to the square meters of body surface area, or to some other index of body size. Relative $\dot{V}O_2$ is commonly used to compare oxygen consumption of individuals who vary in body size. Because $\dot{V}O_{2max}$ is an index of cardiorespiratory fitness, a higher value is indicative of greater aerobic fitness. Cardiorespiratory fitness is defined in the most current edition of the *ACSM's Guidelines for Exercise Testing and Prescription* as the ability to perform large muscle, dynamic, moderate-to-high intensity exercise for prolonged periods.

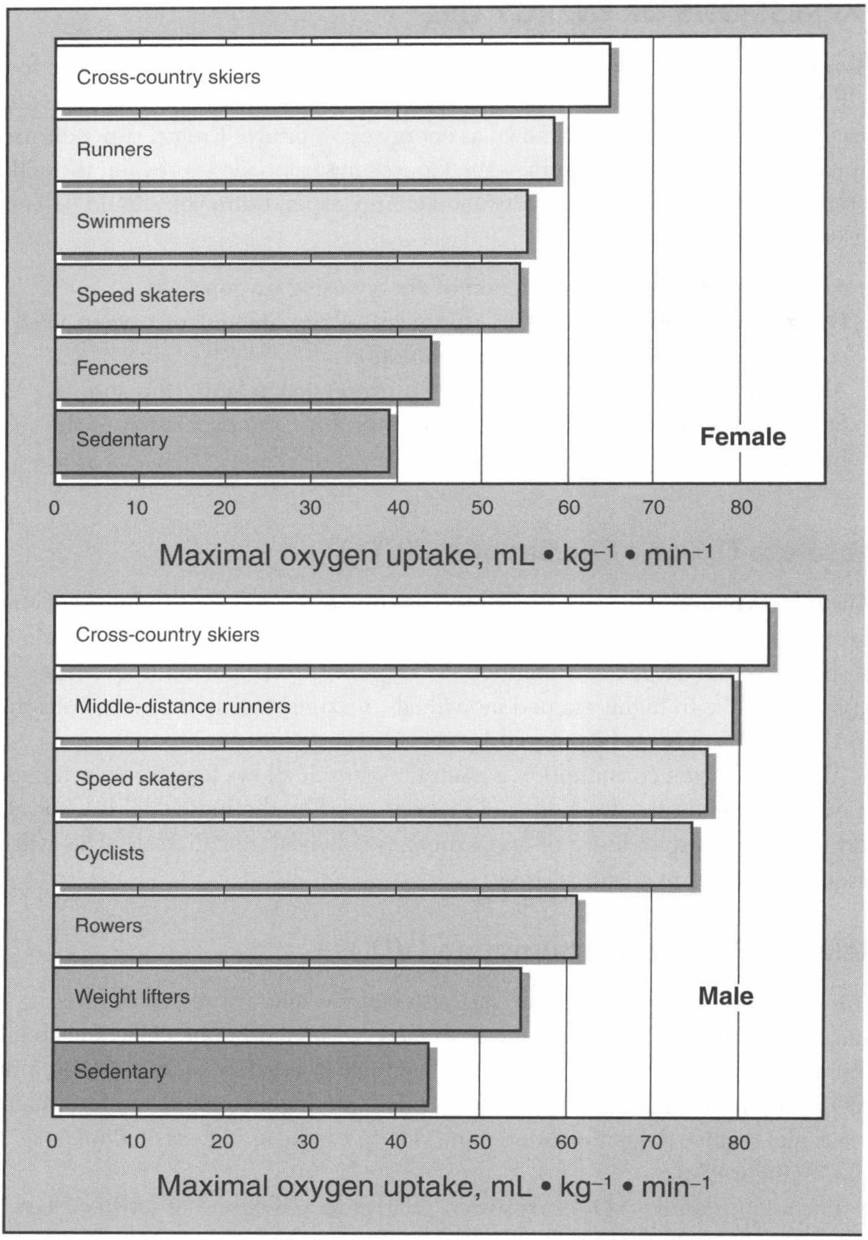


FIGURE 2.2 A Comparison of Relative Oxygen Consumptions. (Adapted with permission from McCardle WD, et al. *Essentials of Exercise Physiology (2nd ed.)*. Philadelphia: Lippincott Williams & Wilkins, 2000.)

You can convert between the absolute and relative oxygen consumption using the following formulas:

$$\text{ABSOLUTE } (\text{mL} \cdot \text{min}^{-1}) \text{ to RELATIVE } (\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1})$$

$$\frac{\dot{V}O_2(\text{mL} \cdot \text{min}^{-1})}{\text{Kilogram (kg) body mass}} = \text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$$

$$\text{RELATIVE to ABSOLUTE}$$

$$\frac{\dot{V}O_2(\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1})}{1000} = \text{L} \cdot \text{kg}^{-1} \cdot \text{min}^{-1} \times \text{kg body mass} = \text{mL} \cdot \text{min}^{-1}$$

Metabolic Equivalents (METs)

Physicians and clinicians commonly use the term *MET(s)* as an expression of relative energy expenditure. A MET is an abbreviation for a metabolic equivalent. One MET is equivalent to the relative oxygen consumption at rest. Therefore, 1 MET = 3.5 $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. METs are calculated by dividing the relative oxygen consumption ($\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) by 3.5. For example, an individual consuming 35 $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ of oxygen during steady-state physical activity is exercising at 10 METs. A MET is a useful expression because it allows for an easy comparison of the amount of oxygen consumption during exercise with that at rest. In addition, there is not any unit of measure associated with MET(s).

Calories

This expression of energy intake and expenditure is commonly used to quantify the amount of energy derived from foodstuffs, as well as the amount of energy expended at rest and during physical activity. A calorie is a very small unit. Most often the measurement kilocalories (kcal) is used. One kcal equals 1,000 calories. An average-sized individual who runs or walks one mile expends approximately 100 kcals. Also, a somewhat useful comparison for weight management is that every pound of fat contains about 3,500 kcals. The kcal can also be expressed in terms of a rate ($\text{kcal} \cdot \text{min}^{-1}$) and is then very useful in terms of the absolute energy intensity of exercise. For instance, one can express the exercise intensity in terms of $\text{kcal} \cdot \text{min}^{-1}$. An exercise of 10 $\text{kcal} \cdot \text{min}^{-1}$ means the individual is expending 10 kcal of energy for every minute they exercise:

$$10 \text{ kcals} \cdot \text{min}^{-1} = \frac{10 \text{ kcals} \cdot \text{min}^{-1}}{(5 \text{ kcal} \cdot \text{L}^{-1})} = 2 \text{ L} \cdot \text{min}^{-1} \text{ oxygen consumption}$$

Energy Stores

The respiratory exchange ratio may be used to help assess the relative use of carbohydrates versus fats in aerobic metabolism (assuming that the amino acids from proteins are not a major supplier of ATP for exercise catabolism). The respiratory exchange ratio (RER) is the ratio of the carbon dioxide produced to the oxygen consumed (RER = $\dot{V}CO_2/\dot{V}O_2$). When the RER is close to 0.70, fats are the primary fuel source for energy metabolism for the exercise. When the RER is closer to 1.0, then the primary fuel source for energy metabolism is carbohydrates.

CARBOHYDRATE STORES

Carbohydrates are stored in three main areas in the body: (1) in the muscle as glycogen, (2) in the liver as glycogen, and (3) in the blood as glucose. The total storage of carbohydrates in the body may be less than approximately 2,000 kcals.

FAT STORES

The human body stores the majority of excess energy intake as fat either below the skin as subcutaneous fat or around the internal organs. The amount of fat that is stored for energy usage can be represented by the body composition, or percent body fat. Even a lean individual may have in excess of 70,000 kcals of stored fat in their body. It takes approximately 3,500 calories to make and store 1 pound of body fat. Stated in reverse, 1 pound of fat can provide the body with 3,500 calories—the amount of energy needed to walk or run about 35 miles!

Net Versus Gross $\dot{V}O_2$

Gross $\dot{V}O_2$ refers to the total oxygen consumption, while net $\dot{V}O_2$ refers to the oxygen consumption for only the activity portion (or minus the resting component). All ACSM Metabolic Calculations (ACSM MetCalcs) provide gross $\dot{V}O_2$ values. In terms of exercise prescription, it may be helpful to use the net $\dot{V}O_2$ value; thus you may need to delete the resting component ($3.5 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$). The concept of $\dot{V}O_2$ reserve used in exercise prescription involves the use of the net $\dot{V}O_2$ value ($\dot{V}O_2$ reserve is similar in concept to the heart rate reserve).

Net $\dot{V}O_2$ may also be used to assess the caloric cost of exercise. Net and gross oxygen consumption can be expressed in relative or absolute terms. The net $\dot{V}O_2$ is calculated by subtracting the resting $\dot{V}O_2$ from the gross $\dot{V}O_2$.

$$\text{Net } \dot{V}O_2 = \text{Gross } \dot{V}O_2 - \text{resting } \dot{V}O_2$$

- The gross rate of oxygen consumption is the total $\dot{V}O_2$ including the resting oxygen requirements, expressed as either $\text{L} \cdot \text{min}^{-1}$ or $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$.
- The net rate of oxygen consumption is the $\dot{V}O_2$ associated with only the amount of exercise being performed exclusive of resting oxygen uptake, expressed as either $\text{L} \cdot \text{min}^{-1}$ or $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$.

Measurement of Oxygen Consumption

The measurement of $\dot{V}O_2$ is typically performed in exercise laboratories or clinical settings using a procedure called open-circuit spirometry. During open-circuit