The Big Reveal

What's Behind Nutrition Labels

By Michael Tinnesand

Nearly all of the foods we eat have a nutrition label that presents the essential values foods contain. The label starts with a serving size and the number of calories per serving, followed by a list of key nutrients, including total fat, carbohydrates, and proteins. Other values may be included, such as calories from fat, saturated fat, trans fat, dietary fiber, sugars, and various vitamins.

But what do all these values mean, and how are they measured? How does this information help us stay healthy?

Calories

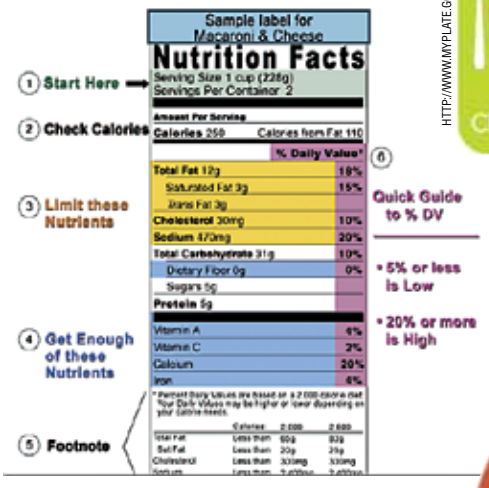
Nearly all of us can be casual about the type and amount of food we consume. I recently stopped at a fast food restaurant and ordered a large caramel coffee frappé. I noticed a brochure near the counter and, as I finished my drink, I read that it contained 680 Calories!

I happen to know that in order to burn 680 Calories at the gym, I would need to spend at least an hour on a stationary bicycle, spinning at high speed. Given that just three of these drinks would exceed my daily limit of total energy required (2,000 Calories), this forced me to pay close attention to the nutritional values of what I eat. But where to begin?

Let's start with calories. Actually, the word "Calorie" (uppercase C) is what chemists call a "kilocalorie," or 1,000 calories (lowercase c). To distinguish between the two, the nutritional calorie is sometimes written as a Calorie—as in this article—as opposed to a calorie. More specifically, one Calorie (kilocalorie) is the amount of energy it takes to raise 1 kilogram of water 1 °C at sea level.

The calorie content of food was determined in the late 1800s by **Wilbur O. Atwater,** an agricultural chemist. He built a device called a respiration calorimeter to make direct measurements of heat released by humans from the food they consumed. At 4 feet by 8 feet, Atwater's calorimeter was big enough to allow a person to step into it. The device measured the amount of heat released by that person, along with the amount of oxygen consumed and carbon dioxide given off.

Using this device, Atwater was able to measure the precise amount of energy contained in thousands of food items. He found that carbohydrates and proteins were worth 4 Calories per gram and fats about 9 Calories per gram. This 4–9–4 system is how labels are determined today. In some cases, dietary fiber is subtracted from the total carbohydrate count because it is assumed that it provides no nutritional calories. Also, alcohol, if present, is accounted for as 7 Calories per gram.



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Calories in, calories out

In case you wonder how many calories you need every day, the answer varies depending on your gender, your age, and your activity level (Table 1).

The calories we need for our daily activities come from a process called metabolism that occurs in the body's cells. Metabolism is a series of chemical reactions that occur when food is broken down in smaller pieces, which also releases energy.

This released energy can also be stored in body tissues for later use. When we consume more calories than our bodies need, calories are stored, primarily as fat.

Gender	Age (years)	Activity Level		
		Sedentary	Moderately Active	Active
Female	4–8	1,200	1,400–1,600	1,400–1,800
	9–13	1,600	1,600–2,000	1,800–2,200
	14–18	1,800	2,000	2,400
	19–30	2,000	2,000–2,200	2,400
	31–50	1,800	2,000	2,200
	51+	1,600	1,800	2,000–2,200
Male	4–8	1,400	1,400–1,600	1,600–2,000
	9–13	1,800	1,800–2,200	2,000–2,600
	14–18	2,200	2,400–2,800	2,800–3,200
	19–30	2,400	2,600–2,800	3,000
	31–50	2,200	2,400–2,600	2,800–3,000
	51+	2,000	2,200–2,400	2,400–2,800

Table 1. Calorie needs by gender, age, and activity level

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This exercise machine, called an ergometer, was used in the laboratory of Wilbur Olin Atwater to measure the amount of calories released by exercising.

But how calories are produced and used—that is, our metabolism—varies from person to person and is mostly affected by how much a person exercises, the amount of fat and muscle in his or her body, and the person's basal metabolic rate—the rate at which a person's body uses energy while at rest.

The basal metabolic rate is responsible for up to 70% of the calories used by our bodies, so it can play a role in a person's tendency to gain weight. For example, a person with a low basal metabolic rate will not use as much energy as a person with a high metabolic rate for the same amount of food.

To a certain extent, the basal metabolic rate is inherited, but it also depends on the amount of muscle and fat present; people with more muscle and less fat generally have a higher basal metabolic rate. Also, people can change their basal metabolic rate by exercising or practicing a sport, which, in the long run, increases the basal metabolic rates of the heart, lungs, kidneys, liver, and the brain. Some outdoor activities can burn a substantial amount of calories (Table 2).

Proteins in food

In addition to calories, the nutrition label also displays the amount of the three main nutrients: proteins, fat, and carbohydrates. Proteins are found in meat, beans, milk, and nuts. Fat is present in vegetable oil, dairy products, and fish. Carbohydrates are found in fruits, vegetables, and cereals.

So how are these nutrients measured? Let's look at proteins first: The standard method for determining the amount of protein in food is called the Kjeldahl (pronounced: Kel-daal) method. Measuring the protein content of food is similar to measuring its nitrogen content because nitrogen in food is contained mostly in proteins.

The Kjeldahl method consists of three steps (summarized in Fig. 1):

1. A sample of food is heated in boiling sulfuric acid (H_2SO_4), which leads to ammonium sulfate [$(NH_4)_2SO_4$], among other products:

$$\text{Sample} + H_2SO_4 \rightarrow (NH_4)_2SO_4\,(aq) + CO_2\,(g) + SO_2\,(g) + H_2O\,(g)$$

Ammonium sulfate is made of ammonium ions (NH_4^+) and sulfate ions (SO_4^{2-}). The ammonium ions contain the nitrogen that was initially present in the sample.

2. The ammonium ions are then converted into ammonia gas (NH_3) by adding sodium hydroxide (NaOH) to the solution of ammonium sulfate:

$$(NH_4)_2SO_4\,(aq) + 2\,NaOH \rightarrow Na_2SO_4\,(aq) + 2\,H_2O\,(l) + 2\,NH_3\,(g)$$

3. The ammonia gas goes inside a condenser and ends up in a flask that contains a solution of boric acid. The ammonia is neutralized by the boric acid, as follows:

$$B(OH)_3 + H_2O + NH_3 \rightarrow NH_4^+ + B(OH)_4^-$$

When all the ammonia has reacted with the boric acid, the amount of borate ions [$B(OH)_4^-$] is determined by titration with a strong acid:

$$B(OH)_4^- + H^+ \rightarrow B(OH)_3 + H_2O$$

The amount of acid needed corresponds to the amount of ammonia that was present. The amount of ammonia is the same as the amount of nitrogen initially present in the sample, which is then used to determine the amount of protein present in the sample.

How much protein do we need every day? The Institute of Medicine recommends that adults consume a minimum of 0.36 grams of protein for every pound of body weight per day. That's about 58 grams for a 160-pound adult.

Fat content of food

The standard method for measuring fat content is called the **Soxhlet extraction**. In this method, food is ground up and continuously

Exercise	Calories per hour
Walking (*3 mph*)	280+
Tennis	350+
Bicycling (*moderate*)	450+
Swimming (*active*)	500+
Hiking	500+
Power walking	600+
Running	700+

Table 2. Calorie-burning chart for various activities

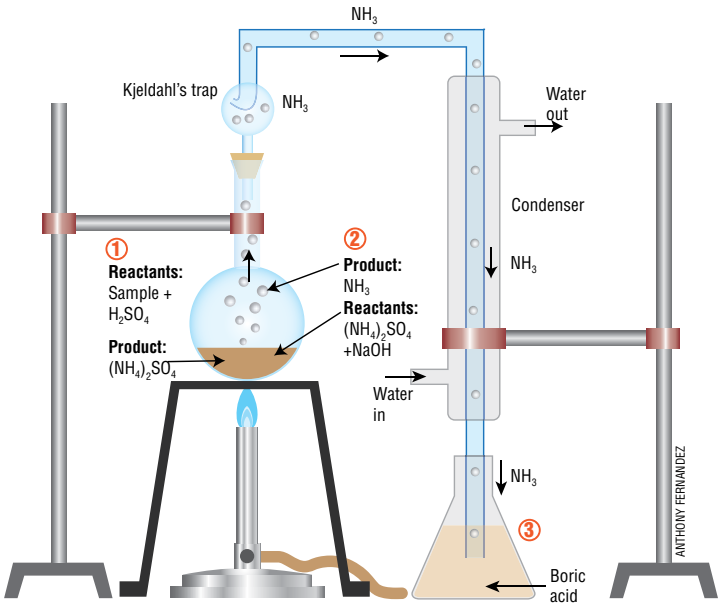

Figure 1. Schematic representation of the apparatus used to estimate the amount of proteins in food by using the Kjeldahl method.

washed with an organic solvent, dissolving only the fat. Although the Soxhlet extraction method has been used for more than 100 years, it is slow and complicated. It can take 6 hours or longer to remove all of the fat.

A new method uses a technique, called nuclear magnetic resonance, to measure fat. Here is how it works: The sample is placed in a strong magnetic field and is bombarded with a pulse of radio frequency. This causes the magnetic moments of the hydrogen nuclei to flip. After the pulse ends, the magnetic moments of the nuclei oscillate, but the magnetic moments of nuclei in fat oscillate at a slightly different frequency than the magnetic moments of nuclei in other substances. So the signal generated by nuclei in fat can be separated from the signals generated by nuclei in other substances present in the sample, and the amount of fat can be determined.

How much fat should we consume? Experts agree that 30% of our daily calories should come from fat. If you consume 2,000 Calories in a day, that means no more than 600 Calories should come from fat. One way to consume 600 Calories from fat is to eat foods that have a total of 67 grams of fat (fat=9 calories per gram, see p. 6).


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When eating out, watch portion sizes and choose meals that contain a balance of proteins, fruits and vegetables, and whole grains. A garden salad provides fiber, vitamins, and minerals without a lot of calories or fat.

Carbohydrate content of food

The amount of total carbohydrates in food has traditionally been calculated rather than measured. Other components of food—such as protein, fat, and water—are measured and added together. This sum is subtracted from the total, and the difference is assumed to be the amount of total carbohydrates.

One problem with calculating the amount of total carbohydrates is that it does not distinguish between carbohydrates used by our bodies to produce energy—such as sugars—and carbohydrates that we cannot digest and are, therefore, excreted, such as fiber.

About half of the calories that you consume should come from carbohydrates. This means that if you consume 2,000 Calories per day, 1,000 Calories should be from carbohydrates. Because each gram of carbohydrate has 4 kilocalories, you would need no more than 250 grams of carbohydrates per day.

Staying healthy

Knowing about calories, proteins, fats, and carbohydrates can help people make informed decisions about the foods they buy and eat, especially if they are overweight or obese. According to the U.S. Centers for Disease Control and Prevention, the percentage of obese U.S. children ages 6 to 11 increased from 7% in 1980 to nearly 20% in 2008, and the percentage of obese U.S. adolescents ages 12 to 19 increased from 5% to 18% during the same period.

The average American diet is high in fat and sugar, so many teenagers consume too much sugar, mainly in the form of sugar-sweetened drinks, such as soft drinks, sports drinks, and energy drinks, along with high-fat foods such as chips, fries, and burgers.

By looking at the nutrition label on food products, you may gain a better understanding of what you are eating and what to include in your diet. *CM*

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Check out the video podcasts on nutrition labels at: www.acs.org/chemmatters