CATTLE, sheep, goats, camels, reindeer, and buffalo are ruminants. Their digestive systems include four-compartment stomachs. The largest is the rumen, from which the term "ruminant" is derived. The other compartments are the reticulum, omasum, and abomasum. The reticulum and rumen are referred to as the reticulo-rumen. Ruminants can convert coarse, fibrous feedstuffs, unsuited for simple-stomach animals, into meat, milk, fiber, and energy. Ruminants can thrive on feeds that are high in fiber and deficient in essential amino acids and B vitamins because of their unique digestive system. The reticulo-rumen provides a suitable environment for the growth and development of bacteria that break down complex carbohydrates, change and synthesize proteins, synthesize vitamins of the B complex, and alter fats. The bacterial fermentation is carried out anterior to the true stomach (abomasum) and small intestine. This seems to be an efficient arrangement for the digestion and utilization of cellulose and provides for digestion of microbial products in the true stomach. Most forage-consuming animals, such as horses and rabbits, have a reverse arrangement.

The number of ruminal bacteria per milliliter (one-thousandth liter) of rumen contents seems to be about 10 billion to 100 billion. There may be approximately 1 million protozoa per milliliter. The capacity of the rumen is in the range of 4 to 10 liters in adult sheep and 100 to 300 liters in adult cattle; the total number of ruminal micro-organisms in an animal therefore is phenomenal. A number of types of ruminal bacteria have been isolated and classified; among them are streptococci, lactobacilli, and selenomonads. Others have been classified into general types, such as cellulolytic bacteria and lactate fermenters. Several others have been described but not completely classified. The isolation and study of the ruminal protozoa is much more difficult, and their exact role in the rumen has not been established. They probably contribute toward the digestion of cellulose and other complex carbohydrates and proteins and store carbohydrates and proteins for later metabolism by the ruminant.

Marked differences exist between ruminants and monogastric—simple stomach—animals in their metabolism of carbohydrates. Carbohydrates are broken down to the simple sugars and absorbed as such from the alimentary tract by monogastric animals, but only small amounts of carbohydrates are handled in a similar manner by
The anatomical location of the reticulo-rumen: a, esophagus; b, cardia; c, esophageal groove; d, rumino-recticular fold; e, anterior pillar of rumen; f, posterior pillar of rumen; g, dorsal sac of rumen; h, vertical sac of rumen; i, reticulum.

ruminants. Most of the carbohydrates, complex and simple, in the diet of ruminants are fermented by bacteria in the rumen to volatile fatty acids (VFAs). At least 600 to 1,200 Calories of energy are absorbed as VFAs from the rumen of sheep every 24 hours. Likewise, some 6 thousand to 12 thousand Calories of energy are liberated in the form of VFAs each day in the rumen of cattle. Thus the VFAs supply a major portion of the energy requirements of the ruminants.

Acetic acid usually is the predominant VFA produced by ruminal fermentation. Propionic and butyric acids are next. Small amounts of valeric acid and branched-chain isomers of butyric and valeric acid also occur usually in rumen contents. Proportions of the VFAs vary with the type of diet and level of feeding. Diets high in soluble or readily fermented carbohydrates favor the production of propionic acid. Diets high in cellulose and a low level of feeding favor the production of acetic acid. Very likely the production of acetic acid in the rumen is correlated positively with the production of butterfat by lactating cows. Propionic acid may be concerned with other processes, such as the production of milk solids. Some VFAs also may be utilized more efficiently than others for fattening of animals.

The quality of protein is important for monogastric animals, and a number of essential amino acids must be supplied by ingested proteins. A considerable portion of the ingested proteins in ruminants, however, is subjected to degradation and alteration by the ruminal micro-organisms during their own metabolism and growth. Urea and other nonprotein nitrogen substances apparently can be
used to a certain extent by the micro-organisms in the synthesis of their body proteins. About half of the protein in the rumen contents of hay-fed sheep may be in the form of microbial protein. A considerable amount of the protein requirements of ruminants is thus met by micro-organisms, which are digested in the abomasum in much the same manner that protein is digested by monogastric animals. Enough vitamins of the B complex and vitamin K normally are synthesized in the rumen of adult ruminants to meet their requirements. Vitamins A, D, and E are not synthesized and must be supplied through dietary or other means.

Fat is another major dietary nutrient. Body fats of cattle and sheep (tallow and mutton suet) have relatively high melting points and chemical stability compared with fats from nonruminants. The melting point and chemical stability of fats are correlated positively with the degree of saturation of the fatty acids—that is, tallow contains a relatively high amount of saturated fatty acids compared with lard. Dietary fats fed to swine also have a pronounced effect on the body fat (lard). Dietary fats with low melting point give rise to soft fat. Feeding experiments with ruminants, however, have shown that dietary fat has little, if any, effect on body fat. Other experiments have demonstrated that unsaturated fatty acids are partly or completely hydrogenated (saturated) by contents of the rumen. These observations appear to be definitely related, and we can conclude that micro-organisms in the rumen affect all major nutrients, other than minerals, consumed by ruminants.

Complex movements of the reticulum and rumen keep the ruminal contents in perpetual movement and are associated with chewing the cud and belching—eructation. Average frequencies of ruminal contractions in cows have been reported to be 168 an hour during eating, 138 an hour during rumination, and 108 during rest. During the process of cud chewing, or rumination, coarse particles of food are passed up through the esophagus from the rumen to the mouth, where the material is remasticated, mixed with saliva, and again swallowed. The total time spent in rumination varies with different diets, but dairy cattle on normal diets spend from about 7 to 10 hours a day in rumination. A. F. Schalk and R. S. Amadon, of the North Dakota Agricultural Experiment Station, described regurgitation (passing of the cud) as resulting from a systemic succession of events that was initiated by a complex reflex mechanism. The reflex—not under voluntary control of the animal—depends on proper stimuli, the kind and amount of food, and rather definite moisture requirements. The reflex appears to be stimulated by the presence of coarse materials in the reticulum. The mechanical events of regurgitation, set in motion by the reflex, include an extra contraction of the reticulum, a contraction of the diaphragm, and reverse motility of the esophagus. The entry of the material into the esophagus also
is aided by increased pressure within the rumen, together with decreased pressure within the esophagus.

Ruminants have to belch. Large volumes of carbon dioxide and methane and lesser amounts of other gases are formed during active fermentation in the rumen. The gases must be expelled, or the ruminant will succumb to bloat. R. W. Dougherty and his coworkers of the New York State Veterinary College and other scientists in several countries have conducted extensive studies of eructation since 1950. They have used various techniques, including X-ray movies of the rumen, reticulum, and esophagus during eructation. Eructation, like regurgitation, is a reflex and not a voluntary act. The stimulus

The gross structure of the reticulo-rumen from a sheep. The muscular structure in the lower center is the anterior pillar; just above it is the most heavily papillated area of the rumen. The reticulum is at the top.
for the eructation reflex is gas pressure in the area around the cardia—the opening of the esophagus into the rumen. The eructation reflex also is complex and apparently is controlled by both initiator and inhibitor components. Dr. Dougherty has shown that eructation can be initiated by applying gas pressure to the area around the cardia and also that eructation can be blocked by applying fluid pressure to the same area. The presence of reflex receptors that are sensitive to gas pressure and not to fluid pressure explains why ruminants belch gas and not fluid, although the cardia is often covered by fluid. The cardia normally is alternately covered and uncovered by fluid as a result of relaxation and contraction of the reticulo-rumen. Eructation also is coordinated with complex movements of the reticulum, rumen, esophagus, and other organs.

Bacteriologists, biochemists, and physiologists have given us some information as to why eructation fails when ruminants are consuming certain feeds, such as lush legumes. Under some conditions, the gas bubbles are trapped within the fluids in the rumen instead of rising to the surface. When that occurs, the rumen contents become frothy and cover the cardia so that it cannot be cleared by the rumen contractions. Eructation then is prevented. We do not know exactly why the gas bubbles are trapped within the rumen contents, but it appears that a number of interacting factors are responsible. Future work will involve research on all phases of ruminal microbiology and physiology. From it we can expect greater understanding of an important class of animals and basic knowledge applicable to other phases of life. (Ivan L. Lindahl)