Notwithstanding this endogenous synthesis, a dietary supply of all vitamins is essential for health.

A deficiency of vitamins may be primary (dietary in origin) or secondary to disturbances in intestinal absorption, transport in the blood, tissue storage, or metabolic conversion. In the following sections, vitamins A, D, and C are presented in some detail because of their wide-ranging activities and the morphologic changes of deficient states. This is followed by presentation in tabular form of the main consequences of deficiencies of the remaining vitamins (E, K, and the B complex) and some essential minerals. However, it should be emphasized that deficiency of a single vitamin is uncommon, and that single or multiple vitamin deficiencies may be associated with PEM.

Vitamin A

The major functions of vitamin A are maintenance of normal vision, regulation of cell growth and differentiation, and regulation of lipid metabolism. Vitamin A is the name given to a group of related compounds that include *retinol* (vitamin A alcohol), *retinal* (vitamin A aldehyde), *and retinoic acid* (vitamin A acid), which have similar biologic activities.

Retinol is the chemical name given to vitamin A. It is the transport form and, as retinol ester, also the storage form. The generic term *retinoids* encompasses vitamin A in its various forms and both natural and synthetic chemicals that are structurally related to vitamin A, but may not necessarily have vitamin A–like biologic activity. Animal-derived foods such as liver, fish, eggs, milk, and butter are important dietary sources of preformed vitamin A. Yellow and leafy green vegetables such as carrots, squash, and spinach supply large amounts of carotenoids, provitamins that can be metabolized to active vitamin A in the body. Carotenoids contribute approximately 30% of the vitamin A in human diets; the most important of these is β-carotene, which is efficiently converted to vitamin A. The Recommended Dietary Allowance for vitamin A is expressed in retinol equivalents, to take into account both preformed vitamin A and β-carotene.

Vitamin A is a fat-soluble vitamin, and its absorption requires bile, pancreatic enzymes, and some level of antioxidant activity in the food. Retinol (generally ingested as retinol ester) and β-carotene are absorbed in the intestine, where β-carotene is also converted to retinol (Fig. 9-24). Retinol is then transported in chylomicrons to the liver for esterification and storage. Uptake in liver cells takes place through the apolipoprotein E receptor. More than 90% of the body's vitamin A reserves are stored in the liver, predominantly in the perisinusoidal stellate (Ito) cells. In healthy persons who consume an adequate diet, these reserves are sufficient to meet the body's demands for at least 6 months. Retinol esters stored in the liver can be mobilized; before release, retinol binds to a specific retinol-binding protein (RBP), synthesized in the liver. The uptake of retinol/RBP in peripheral tissues is dependent on cell surface receptors specific for RBP. After uptake, retinol binds to a cellular RBP, and the RBP is released back into the blood. Retinol may also be stored in peripheral tissues as retinol ester or may be oxidized to form retinoic acid, which has important effects on epithelial differentiation and growth.

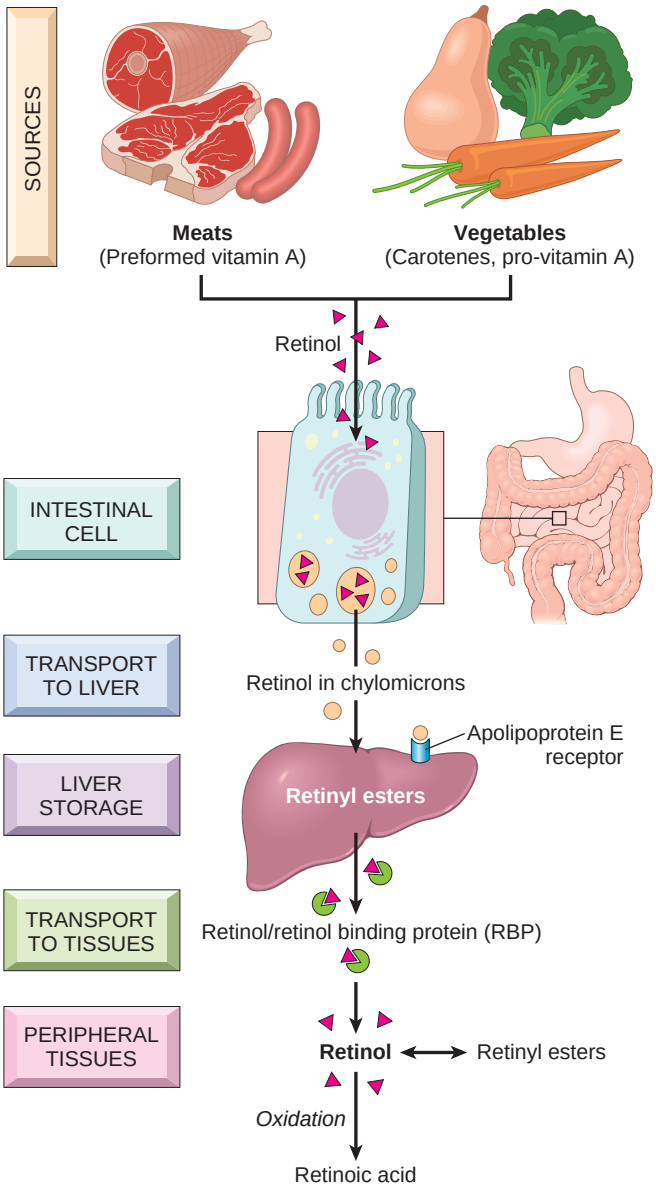

Figure 9-24 Vitamin A metabolism.

Function. In humans, the main functions of vitamin A are the following:

- *Maintenance of normal vision.* The visual process involves four forms of vitamin A–containing pigments: rhodopsin in the rods, the most light-sensitive pigment and therefore important in reduced light, and three iodopsins in cone cells, each responsive to specific colors in bright light. The synthesis of rhodopsin from retinol involves (1) oxidation to all-*trans*-retinal, (2) isomerization to 11-*cis*-retinal, and (3) covalent association with the 7-transmembrane rod protein opsin to form rhodopsin. A photon of light causes the isomerization of 11-*cis*-retinal to all-*trans*-retinal, which dissociates from rhodopsin. This induces a conformational change in opsin, triggering a series of downstream events that generate a nerve impulse, which is transmitted via neurons from the retina to the brain. During dark adaptation, some of the all-*trans*-retinal is reconverted to