Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
1985 Volume VII: Skeletal Materials- Biomineralization

The Calcium Cycle

Curriculum Unit 85.07.08
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INTRODUCTION

This unit is designed to be part of the Ecology course which is taught by High School in the Community at the West Rock Nature Center for four hours a day during the last quarter of the school year, The present ecology course involves both theoretical and practical studies relating to the earth and how it works. We will trace calcium in the biosphere from its location in igneous rocks in the early history of the earth to its location in the skeletons of high school students at the Nature Center. In the process of studying the transport and deposition of calcium we have a vehicle which touches on many of the important concepts we are teaching and relates to some of the hands-on activities the students are involved in.

Some of the connections between the calcium cycle and the Ecology course are:

> Geology: Many of the students have no idea of the age and history of the earth and the great changes which it has gone through. How the calcium stored in the rocks in northwestern Connecticut came to be there touches on much of this chemistry: Most of the students have had very little exposure to chemistry, yet it is important in the study of ecology. Using the study of calcium, some simple chemical principles can be introduced such as the fact that calcium is intimately associated with carbon dioxide (CO2), as the solid calcium carbonate (CaCO3), and therefore is involved with life and life forms.
> Cycles: The concept that all materials on earth come from somewhere and must go somewhere is central to ecology. Calcium has its own biogeochemical cycle which is not treated in the materials we currently use.
> Agriculture: Growing a garden and raising animals, including chickens, are important practical activities in this course. Calcium relates to soil fertility and to the ability of chickens to produce eggshells. Also, since humans can't move a muscle without the presence of calcium in the muscle, it relates to the students' ability to do agricultural work.
> Nutrition: Calcium is an essential element in human nutrition. As such it relates to the selection of which foods to produce. (.Nutritionists often call calcium a mineral; while a geologist or mineralogist will insist this is not correct. See the chemistry section below.)

"Drink your milk and go play in the sunshine," generations of mothers have told their children. In doing this they have shown an understanding of:

The importance of calcium in the diet of growing children,

The importance of milk as a source of calcium, [2] and

The importance for proper calcium nutrition of vitamin D, developed on the skin in the presence of sunlight, and exercise.

Science News3 reported early in 1985 three studies which relates calcium to diseases of older people, osteoporosis, atherosclerosis, and colorectal cancer.

One [4] study showed that milk may be better than calcium supplements at slowing or curbing bone loss or osteoporosis in postmenopausal women because milk doesn't suppress bone renewal the way the calcium supplements, which are calcium carbonate, do.

Another study, [5] done with goats, showed that the calcium in milk, in the absence of excess vitamin D, may impart some protection against atherosclerosis (hardening of the arteries) and clogging of blood vessels with plaque. The third study [6] showed that a group of men who had higher intake of calcium rich foods and vitamin D had lower rates of colorectal cancer than those who ingested less calcium and vitamin D.

From birth to death calcium is an essential element for human beings. Besides its presence in bones and teeth, the mineralized tissues which contain 99% of the body's calcium, it is present in ionized form in the blood, extracellular fluids and within the cells of soft tissues such as muscles. It is necessary for the release of energy in muscular contraction, for nerve transmission and the regulation of heart beat, must be present for blood to clot, and influences the transport function of cell membranes. The proper balance of calcium with sodium, potassium and magnesium ions maintains muscle tone and controls irritability.

Shortages of calcium in the diet can lead to stunting of growth or abnormal development of bones such as rickets in the young.

CHEMISTRY OF CALCIUM

What is calcium? It is a chemical element, an alkaline earth metal, number twenty in the periodic table.

It is the fifth most abundant element in the earth's crust and in the human body. It is not found in its metallic form on the earth's surface, but is found associated with other elements and molecular species as solids in minerals, and in ionized form complexed with a variety of other compounds. A mineral is a naturally formed substance that has a specific chemical composition and atomic structure with characteristic physical properties. Examples of calcium containing minerals are calcite and aragonite which have the same chemical composition, CaCO3, but different crystal structure (called polymorphs) and hydroxyapatite, Ca5(PO4)3 (OH).

These minerals are the most important ones for the purpose of this unit. [7] Calcite and aragonite are the minerals produced by sea creatures, invertebrates, to make their shells, and by birds and reptiles, vertebrates, to contain their eggs. Limestone and marble can have the same chemical composition and their connection to shells will be discussed later. Hydroxyapatite is the mineral in bones and is also common in many varieties of rocks. As a mineral, calcium is locked up or sequestered in relatively insoluble compounds.

Calcium is "active" and relatively mobile in its other form as a positively charged particle, or cation. An ion is an atom or group of atoms which has a net charge because the number of negatively charged electrons present is different from the number of positively charged protons in the nucleus. Calcium is a relatively large atom with only two electrons in the outer orbit. These tend to be lost creating the calcium cation, Ca^{++}, which is attracted to and loosely held by molecules or substances which have negatively charged sites. In these situations calcium cations are said to form complexes which vary in the strength with which the calcium is held. Ionic Calcium can be found in fresh and salt water, held by certain proteins in the blood and extracellular fluid of animals and adsorbed onto clay and other colloidal particles in the soil. (Water is a dynamic polar molecule with a partial negative charge on the oxygen.) In the human body less than 1% of the calcium is in the active, ionized form, but it is vitally important.

In the human body and in the earth's crust, the vast majority of calcium is present in the sequestered form. In the body the mineral in bones can be solubilized creating ionized calcium to maintain the critical level in the blood. In the earth's crust the calcium containing minerals in rocks can be slowly dissolved to provide the Ca^{++} in solution in lakes, rivers and oceans and adsorbed in the soil. Most of this calcium is then stored again as a mineral. For example, it is estimated that of the apatite, calcium phosphate, minerals that have been dissolved in the sea, 99.8% have been reprecipitated in some way.

Where the calcium is and how it moves from one form to another is the next step in understanding this fascinating and essential element.

CALCIUM, GEOLOGY AND THE HYDROSPHERE

In the earth's crust calcium makes up about 3.4% of the mass, exceeded by iron, 4.7%, aluminum, 7.5%, silicon 25.8% and oxygen 49.5%. Calcium, one of the elements of the original crust of the earth, is today found in igneous rocks as calcium silicates and in sedimentary and metamorphic rocks as calcium carbonates. The processes involved in weathering rocks, especially where some acid is present, as carbon dioxide dissolved in water or from growing lichens, are able to free some calcium from its sequestered location and send it on its way as a cation attracted to a water molecule.

Water carries the calcium cations from the highlands to the oceans. Concentrations of Ca^{++} in fresh water range from 0.01 to 0.1 millimolar. [8] High concentrations of calcium and/or magnesium cations in fresh water create what is called hard water. In seawater Ca^{++} concentrations are 100 to 1000 times higher at 10 millimolar, with slightly greater concentrations in the deeper, colder water. This calcium then spends, on the average, one million years in the ocean before it appears on land again. The calcium ion remains in the sea water until it is precipitated out as calcium carbonate or (more rarely) as calcium sulfate, gypsum, which when heated becomes plaster of paris.

The upper levels of the ocean are supersaturated with Ca^{++} and carbonate, Ca^{--3}, ions. This means that all of these species which can be held in solution are in solution. The amount varies with different locations and conditions with saturation being greatest in warm shallow water with lower levels of CO_2, because of photosynthesis and temperature. In these locations $CaCO_3$ precipitates readily either inorganically or with the help of organisms. Organisms can accomplish this by building shells. This is one of the processes called biomineralization. As the organisms die their hard or mineralized parts, shells, fall to the ocean floor and accumulate or dissolve depending on depth, temperature and pressure. Shells and such which fall to the bottom of the deep parts of the ocean are most often redissolved because the deeper waters can hold more CO_2 and are colder. The division between where the $CaCO_3$ dissolves and accumulates is called the lysocline.

The mechanisms which cause $CaCO_3$ accumulation in water are various, fascinating and not fully understood. Microscopic life, heterotrophic and photoautotrophic, is responsible for much of the deposition. Simkiss says the oldest evidence for life on earth is probably the "algal limestones" of Rhodesia (now Zimbabwe) which are dated as 2.7 billion years old. [9] Thomas H. Huxley, in a 1868 lecture to working men titled "On a Piece of Chalk," [10] argues that the tiny organism Globigerina is responsible for much of the limestone which underlies Europe. Kormondy [11] states that some aquatic plants occurring in alkaline waters release $CaCO_3$ as a by-product of photosynthetic assimilation. As an example he says that 100 kg of *Elodea canadensis* can precipitate 2 kg of $CaCO_3$ in 10 hours of sunlight under natural conditions.

The deposited $CaCO_3$ can be mixed with other sediments from the sea or washed from the land depending on its location.

How does the calcium get back on land after if has done its time in the ocean, Obviously some is brought back as birds, animals and man harvest seafood, especially shellfish, and eat it on land, discarding the shells. The Indians did this when they harvested fish and planted it under their corn. (The form of calcium is different in fish skeletons. See below.) The High School in the Community gardens make use of compost which is created by pigs from supermarket and resturant wastes and leaves. Seashells are one of the few recognizable items in the compost, slow release calcium sources.

The majority of calcium, however, takes a different route back to the land. It takes a ride on a major geological process. The movements of crustal plates and continental land masses with various upthrusts has brought many of these accumulated $CaCO_3$ deposits to or near the surface as limestone or, if it has undergone metamorphosis by pressure and temperature, as marble. Much of Europe and the central part of the United States east of the Mississippi River are underlain with limestone. The white cliffs of Dover are limestone. The northwestern part of Connecticut has bands of marble sandwiched between layers of metamorphosed sandstone and shale, indicating past open ocean sedimentary environment in a warm climate.

Calcium can also make it back to land through the evaporation of brackish inland seas and the processes which produce reefs.

AGRICULTURE

To understand how calcium gets into our bodies we have to look at calcium on and in the land. In humid, high rainfall regions like New England, most of the calcium cations have been leached out of the soil root zone by water and the addition of some calcium, often in the form of ground limestone, is necessary for good growth of most food plants. Although the amount of calcium needed by plants is small (calcium is 0.2 to 3.5 of the dry weight of plants and living plants are usually more than 60% water), calcium performs other important functions in the soil that make it useful and necessary.

Calcium cations are used to decrease the acidity and raise the pH of the soil. The pH is a measure of the hydrogen ion concentration. The pH scale runs from 0 to 14 with the greater the H^+ concentration, the lower the p. Hydrogen ions are given off by plant roots as they grow. Among the variously sized rock particles, organisms of all sorts and organic matter in the soil are colloidal particles of clay and humus which have negative charges on their surfaces. Cations are adsorbed and held on these negatively charged sites. An acid soil has most of these sites filled with hydrogen ions. In a good agricultural soil about 60-70% of these sites should be filled with calcium cations, 10-20% should be filled with magnesium cations, 10-15% with hydrogen cations, 3-5% with potassium cations and the remainder with micronutrients.

Besides adjusting the pH and being available for plants, proper calcium levels improve soil structure, make phosphorus and micronutrients more available, and improve the environment for microorganisms. Calcium is said to aid the growth of symbiotic and non-symbiotic nitrogen fixing bacteria which is why liming is important for the growth of legumes, whose roots host nitrogen fixing bacteria.[12]

Limestone is relatively insoluble. How does spreading ground limestone on the soil and mixing it in make calcium ions available? Carbon dioxide is given off whenever living things respire. Plant roots and soil organisms of all sizes give off carbon dioxide which combines with water in the soil to produce carbonic acid which is able to dissolve the limestone, freeing the calcium as a cation to find an alternate negatively charged site to attach to. One important aspect of the limestone applied to the soil is particle size. The smaller the particles the larger the total surface area of limestone for the chemical activity to take place on, making for faster dissolution.

Often limestone contains magnesium as well as calcium in the form of carbonates and oxides. This limestone is called dolomite, is the kind that is found in northwestern Connecticut and is the kind often needed in Connecticut soils to reach the approximate relationships indicated earlier. (Magnesium is the central element in the chlorophyll molecule and is found in every green cell of a plant.) The analysis of limestone from Canaan, CT is magnesium oxide 18%, calcium oxide 28% and carbonates of calcium and magnesium 90%.

On the colloidal particles one cation can be replaced by another. If all ions are present in equal concentration potassium ions will replace sodium ions, magnesium ions will replace potassium, calcium will replace magnesium and hydrogen will replace calcium ions. Since hydrogen is not only given off by plant roots, but is produced in the forming of carbonic acid it is necessary to have a good supply of calcium and magnesium ions in the soil to keep their levels above that of the hydrogen on the colloidal sites.

Calcium is taken up by the roots of plants either directly from the particles or after it has moved into the soil solution. Ca^{++} moves into roots because of its greater concentrations outside the roots and because of membrane potential. Both active and passive transport are involved in getting Ca^{++} into the plant.

As noted before the calcium content (need) of plants varies. In general monocots, grasses such as corn and other grains, need less calcium than dicots, most other food plants. For example, calcium content is given as 1.3% in alfalfa and 0.82% in current year leaf and twig growth of white oak, both dicots, and only 0.40% in corn. In the plants the Ca^{++} is said to be phloem-immobile, meaning that once it reaches the leaves via the xylem which carries materials up from the roots, it is not readily exported from the leaves via the food conducting tissues. This implies that most of the calcium taken up by trees and other perenials is returned to the ground with the leaf fall to be recycled as microorganisms decompose the leaves. Kormondy[13] reports a study of the nutrient budget of Scots pine plantation in England. For over the 55 years from planting, the total uptake by trees and ground flora was 3043 kilograms per hectare and the total return to litter and soil was 2565 kilograms per hectare. (Deborah Barnes has a good diagram of the Ca^{++} cycle in plants in her unit.)

In the plant, calcium as well as magnesium, form salts of pectic acid which make up most of the middle lamella that binds adjacent plant cells. This makes calcium an important part of the physical structure of plants. Calcium in plants also functions as an enzyme cofactor and has a direct effect on the physical properties of the cellular membranes. If there is a deficiency of calcium the membranes seem to lose their integrity. The solutes within the membranes or the cells then leak out.

The calcium in plants can be returned to the soil with the falling leaves, as mentioned, or can be stored in a woody part until it falls and rots or is burned, or the calcium can be ingested by an animal which eats the plant. If wood is burned the ash content is typically 0.1-3.0%. Of this, 30-60% contains calcium in the form of calcium oxide. This is why wood ashes are another good source of calcium and a way to raise the pH of the soil. However since they also contain 10-30% potassium oxide and other elements, often in soluble forms, ashes have to be used sparingly to avoid excess potassium and salinity.

NUTRITION

It has already been said that the calcium content of plants varies. In general dark green leafy vegetables have more calcium than other plants. The United States Department of Agriculture book *Composition of Foods* lists, with other items, the calcium content of all foods in milligrams per 100 grams edible portion. This makes it easy to figure percentage composition. Each 100 milligrams is 0.1%. Turnip greens are often said to be one of the best vegetable calcium sources. They are 0.246% calcium raw (246 milligrams per 100 grams), and the percentage goes down to 0.184% if they are cooked in a small amount of water for a short time and drained, More water and longer cooking further reduce the calcium content. One of the highest percentages of calcium in a land plant is found in lambsquarters, *Chenopodium album* , a very edible and very common weed. Its presence is said to indicate good fertile soil. It may be that only in fertile, well balanced soil can this plant accumulate its 0.309% calcium, which is almost three times the 0.118% calcium in whole fluid milk. Green amaranth, another common garden weed, has 0.267% calcium. It is used as a vegetable in China and the seeds of a related plant were used as a grain by the Aztecs.

A study of the *Composition of Foods* makes it clear that the highest calcium contents for whole foods are in foods from the sea. Kelp seaweed has the highest percentage listed for any whole plant food. It is 1.093% calcium, with other seaweeds ranging from 0.885 to 0.296%.

As we move from bacteria to plants to animals the weight percentage of calcium increases. In all organisms oxygen, carbon, hydrogen and nitrogen make up over 95% of the weight. Calcium, phosphorus, potassium and sulfur are the next most common elements in living things. *Biology of Plants* gives the percentages of fresh weight composed of the four major elements plus phosphorus and sulfur, for humans, alfalfa and bacteria. This tells us how much room is left for calcium, potassium and all the other elements found in living things. The six listed, CHNOPS by their chemical symbols, make up 97.90% of humans, 99,60% of alfalfa and 99.72% of bacteria. Calcium makes up 1.5% of the average human body.

Animals accumulate calcium from the foods they eat. Herbivores such as cows must get all their calcium from pasture, hay and grains they eat. Carnivores or omnivores can get their calcium from animals or, in the latter case, also from plants. A 150 pound person has about 2.25 pounds of calcium in the body of which 99 is present in the bones and teeth which leaves about one third of an ounce of calcium in all other locations in the body. The edible portions of most meats contain about 0.01 calcium. This makes many vegetables better sources of calcium than meats, and may be why it takes an herbivore like a cow, which consumes prodigious amounts of vegetation to concentrate enough calcium to produce milk in quantity over the long term. It also explains why carrnvores such as dogs chew on bones. In all animals, except for periods of growth, the calcium taken in food and drink equals the calcium excreted in feces, urine and sweat and in any milk produced. A balance is maintained in a healthy animal.

Of the calcium ingested in foods by humans, [14] usually as little as 20-30% is absorbed and it can be as low as 10% Calcium is primarily absorbed from the food into the body in the duodenum (the first part of the small intestine) in an acid medium. As with the parent rock and the limestone in the soil, acids are necessary to free calcium from its sequestered state. In general, the absorption of calcium is reduced in the lower part of the intestinal tract as the food content becomes more alkaline (higher pH). There is evidence, however, that some calcium can be absorbed in the colon. The calcium in the fibrous plant cell wall only becomes available when the cell wall structure is digested by microbial fermentation in the colon. This fermentation changes calcium into an available form. It also suggests a connection to the digestive process of cows and other ruminants where microbial fermentation in the rumen, an antechamber of the stomach, is an essential early step in the digestive process. Ruminant animals, goats, sheep, camels as well as cows, provide most of the world’s milk.

Calcium is absorbed by active transport, which requires energy, and by passive diffusion. It is absorbed only if it is present in a water soluble form in the intestine and hasn’t been precipated by something else in the food. Whatever is not absorbed leaves with the feces.

There are six factors which can increase calcium absorption. Vitamin D, the sunshine vitamin, stimulates calcium absorption in the intestines. Lactose, or milk sugar, enhances the absorption of calcium in people with normal lactase, an enzyme which splits lactose into galactose and glucose for digestion. It is thought that lactose functions either by forming a sugar-calcium complex which can be transported across intestinal mucosa or by preventing the precipation of insoluble calcium complex as the contents of the intestinal tract change from acid to alkaline. This obviously relates to the importance of milk as a source of usuable calcium. However, in humans with lactase deficiency, lactose inhibits calcium absorption.

A high intake of protein causes a greater amount of calcium to be absorbed than with a low intake of protein. Certain a ino acids act upon intestinal pH and upon the formation of the soluble complex with calcium facilitates calcium absorption. Also, moderate amounts of fat increase transit time through the digestive tract which makes for more time for “mineral” absorption. (Studies of the diet of Cro-Magnon people indicate that these Stone Age folks ate three times the protein, half the fat and twice the fiber and calcium as present people do. The researcher noted that our diet has evolved much faster than our genes have.) [15]

The acidity of gastric juices, specifically the hydrochloric acid released by the stomach, lowers the pH of the contents of the digestive tract in the small intestine and favors calcium dissociation and hence absorption. The final factor which can increase calcium absorption is the physiological state. The greater the need and the smaller the dieta supply, the more efficiently the body absorbs calcium from the food. Absorption is also increased during periods of growth, but it is decreased after middle age and the response of increased absorption to decreased intake is blunted in elderly persons.

Other factors decrease calcium absorption. Some of these can be inferred from those which increase absorption. These include lack of vitamin D, rapid passing of food through the intestinal tract, alkaline conditions in theintestinal tract which encourage the formation of insoluble and nonabsorbable calcium phosphate, and lastly, some studies suggest that too much fat in the diet may contribute to lower calcium absorption.

Several acids present in food can contribute to lower calcium absorption. Oxalic acid in the digestive tract combines with calcium to form an insoluble compound, calcium oxalate, so the calcium cannot be absorbed. Oxalic acid is present in appreciable amounts in rhubarb, spinach, chard and beet greens. In a similar way, phytic acid combines with calcium to form calcium phytate which is insoluble. Phytic acid is a phosphorus containing compound found principally in the outer husks of cereal grains, especially oatmeal. There is also some evidence that fiber itself, aside from the phytic acid it contains, may decrease calcium absorption from the small intestine.

Exercise stimulates bone cell production. A lack of exercise and lack of weight bearing on the legs cause a decrease in the body's ability to absorb calcium. Weightlessness, as in space flight, causes bone loss.

Absorption of calcium tends to decrease and its excretion tends to increase with mental stress. People under physical or emotional duress need a higher intake of calcium to maintain proper calcium equilibrium. Some drugs can also decrease calcium absorption.

Some studies suggest that a high ratio of phosphorus to calcium may affect bone or calcium metabolism. Phosphorus consumption under 2.0 grams per day with adequate calcium doesn't appear to cause ill effects. However, in the teenage growth years, when the need for calcium is high, there may be reason to worry about the replacement of milk in the diet by phosphorus containing cola beverages.

How much calcium should a person take in daily? This will vary, not only because of the above factors, but also with age and for women, with pregnancy, lactation and menopause. The basic recommended daily allowance in this country is 800 milligrams. This is higher than it is in some other parts of the world because of the abundance of food sources of calcium here.

An additional 400 milligrams is recommended for children between 11 and 18 years of age and for pregnant or lactating women. It is often recommended that older women take in 200 milligrams above the basic level.

Once it has been absorbed through the intestinal wall, the calcium ion is transported by the blood to the fluids bathing the tissues of the body, including the bones, and to the cells wherever needed. Most of the calcium is used by the bones, where the calcium is in equilibrium with the calcium in the blood. The average male has about 1200 grams or about 2.6 pounds of calcium and the average female has about 1000 grams or 2.2 pounds. As stated earlier, 99% of this is in the bones and teeth and less than 1% is in the fluids. Of that 1%, about one half is ionized and physiologically active and the other half is non-ionized and physiologically inert, mostly bound to proteins, primarily albumin.

Some of the calcium in the bones is in a form which is rapidly exchangeable and is available when needed to maintain the proper levels of calcium in the blood. It can be stored again when there is excess calcium input. Parathormone and calcitonin are hormones which act to control the flow of calcium into and out of the bones and maintain serum calcium at a normal concentration of 10 milligrams per 100 milliliters of blood serum.

The biomineralization process in vertebrates differs from that in invertebrates. The mineral made by the higher animals as an internal skeleton is hydroxyapatite, Ca5(PO4)3 (OH). It is 40% calcium and 18% phosphorus by weight. Phosphorus makes up about 1.2% of the human body, slightly less than calcium, and a greater percentage of it is in places other than the bones. About 6% is associated with the muscles, especially in the energy storing compound adenosine triphosphate, ADP. In addition phosphorus has more functions than any other “mineral” element in the body. This much wider distribution of phosphorus in the bodies of animals makes meats a good source of this element.

By weight, calcium is present in the body at one half the percentage it is in the earth’s crust. Phosphorus, however is much rarer in the earth’s crust. It is present in the body at ten times the weight percent it is present in the crust. In fact, the bones of vertebrates are the major store of phosphorus in the world. (In *Brave New World* by Aldous Huxley, the bodies of the dead are burned for phosphorus recovery.)

Except for that stored in the bones, the dynamic calcium balance in the body requires that over time all the calcium taken in must be excreted. Most of this is in feces and urine, which through outhouse, septic system or sewage treatment plant reenters the soil or water to be cycled again through plants, animals, geology or agriculture.

NOTES

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1. In the several places I have used mineral as a nutritionist would, I have put it in quotation marks.
2. I am aware that this statement applies only to those who are genetically able to digest milk and geographically and culturally able to raise dairy animals. A study of non-dairy sources of calcium around the world would be fascinating. Examples include ground seashells in some African diets, calcium containing rock ground with corn in Central and South America, the great use of plants and animals from the sea in countries on the western Pacific and many others.
3. *Science News* , March 2, 1985, p. 141.
4. Ibid, study done at Creighton University School of Medicine, Omaha, Nebraska
5. Ibid., study done at Iowa State University in Ames.
6. Ibid., study done at University of California at San Diego.
7. Simkiss (1975) has a good table of types of calcified tissues.
8. One millimolar, mM, is one thousandth of a mole of solute per liter of solution. A mole is $6.022X10^{23}$ of something. A 1.0 mM solution of calcium ions has $6.022 X 10^{23}$ ions in each liter of solution.
9. Simkiss, p. 2.
10. Huxley, pp 1-36.
11. Kormondy, p. 41.
12. Walters, p. 181, Janick, p. 82.
13. Kormondy, p. 56.
14. Krause. This book provided most of the nutritional information on Calcium.
15. This study was published in the *New England Journal* of Medicine early in 1985 and was widely reported in the popular press.

Ca^{++} concentration mM (see note 8)

(figure available in print form)

The Calcium Cycle

(figure available in print form)

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RESOURCES

Nutritional information on calcium is available from the University of Connecticut Cooperative Extension Service, 670 Wintergreen Ave., Hamden. They also have information on agriculture and can, for a fee, provide soil tests.

Free soil tests, pH etc., are available from the Connecticut Agricultural Experiment Station on Huntington St., New Haven.

KAL makes a self check up kit, Calcium test. I got one at Edge of the Woods food store on Edgewood Ave. in New Haven.

The West Rock Nature Center on Wintergreen Ave, a New Haven park in Hamden, is the site of the High School in The Community Ecology class and an important resource for the study of ecology.