

14<sup>th</sup>  
Edition

# BIOCHEMISTRY

## FOR STUDENTS



**VK Malhotra**



JAYPEE

# Contents

---

<b>Chapter 1: Biophysics</b>	<b>1</b>
Hydrogen Ion Concentration, pH	1
• Buffers	3
• Blood Buffers	8
• Osmosis and Osmotic Pressure	10
Colloids	15
• Properties of Colloidal Solutions	15
Surface Tension	15
• Role of Surface Tension	16
Absorption	16
Viscosity	16
<b>Chapter 2: Chemistry of Carbohydrates</b>	<b>17</b>
Carbohydrates	17
Functions of Carbohydrates	17
Classification of Carbohydrates	17
• Monosaccharides	17
• Oligosaccharides	37
Polysaccharides	41
• Homopolysaccharides (Homoglycans)	42
Heteropolysaccharides (HetEroglycans)	45
<b>Chapter 3: Chemistry of Lipids</b>	<b>50</b>
• Classification and Functions of Lipids	51
Simple Lipids	51
• Fatty Acids	52
• Prostaglandins	55
Compound Lipids	59
• Phospholipids	59
Derived Lipid	64
• Terpenes	65
• Steroids	65
• Antioxidant System	66
<b>Chapter 4: Chemistry of Amino Acids and Proteins</b>	<b>70</b>
Chemistry of Amino Acids	70
• Classification of Amino Acids	71
• Peptides	75
Proteins	80

<b>Chapter 5: Hemoglobin</b>	<b>96</b>
Porphins	96
Porphyrins	97
Hemoglobin	97
• Functions of Hemoglobin	98
Porphyria	107
<b>Chapter 6: Enzymes</b>	<b>113</b>
• Coenzymes	114
<b>Factors Influencing the Rate of Enzymatic Reactions</b>	<b>116</b>
• Effect of Substrate Concentration	117
<b>Enzyme Activity</b>	<b>123</b>
• Turnover Number	123
<b>Enzyme Inhibitions</b>	<b>124</b>
• Competitive Inhibition	124
• Noncompetitive Inhibition	125
• Uncompetitive Inhibition	126
<b>Catalytic Site or the Active Sites of the Enzymes</b>	<b>127</b>
<b>Enzyme Induction</b>	<b>128</b>
• Constitutive Enzymes	128
• Inducible Enzymes	128
• Therapeutic Enzymes	130
<b>Diagnostic Value of Plasma Enzymes</b>	<b>130</b>
<b>Chapter 7: Biological Oxidation</b>	<b>132</b>
Mixed Function Oxidases	134
High Energy Compounds	135
Respiratory Chain	136
<b>Chapter 8: Metabolism of Carbohydrates</b>	<b>143</b>
Glycolysis	143
• Salient Features of Embden–Meyerhof Pathway	145
<b>Citric Acid Cycle</b>	<b>147</b>
• Conversion of Pyruvate to Acetyl CoA	147
<b>Energetics</b>	<b>151</b>
<b>Glycogenesis</b>	<b>156</b>
• Glycogen Synthetase	158
• Glycogenolysis	159
• Liver Phosphorylase	160
• Cori Cycle	160
<b>Gluconeogenesis</b>	<b>162</b>
<b>Galactose Metabolism</b>	<b>164</b>
<b>Galactosemia</b>	<b>165</b>
<b>Fructose Metabolism</b>	<b>165</b>
<b>Lactose Synthesis</b>	<b>166</b>
<b>Uronic Acid Pathway</b>	<b>167</b>
• Pentosuria	168

	<b>Regulation of Blood Glucose 168</b>	
	• Ways by which Sugar is Added to the Blood 168	
	• Ways by which Sugar is Removed from the Blood 168	
	• Glycosuria 171	
<b>Chapter 9:</b>	<b>Metabolism of Lipids</b>	<b>177</b>
	<b>Plasma Lipoproteins 177</b>	
	• Absorption of Fats 178	
	• Oxidation of Fatty Acids 181	
<b>Chapter 10:</b>	<b>Metabolism of Proteins</b>	<b>202</b>
	<b>Digestion and Absorption 202</b>	
	• Digestion of Protein by Various Enzymes 202	
	<b>Urea Cycle (Krebs–Henseleit Cycle) or</b>	
	<b>Ornithine Cycle 207</b>	
	<b>Glycine 213</b>	
	<b>Methionine 218</b>	
	<b>Cysteine and Cystine 218</b>	
	• Metabolic Role of Cysteine 218	
	<b>Phenylalanine and Tyrosine 220</b>	
	• Metabolism of Phenylalanine and Tyrosine 221	
	<b>Tryptophan 228</b>	
	• Metabolism of Tryptophan 228	
	• Hartnup Disease 230	
	<b>Leucine, Isoleucine and Valine 230</b>	
	• Metabolism of Branched Chain Amino Acids 230	
<b>Chapter 11:</b>	<b>Nucleic Acid—Chemistry and Metabolism</b>	<b>232</b>
	• Pyrimidine Bases 232	
	• Purine Bases 233	
	• Pentose Sugars 233	
	• Nucleoside 234	
	• Nucleotides 234	
	<b>Nucleic Acids 235</b>	
	• Deoxyribonucleic Acid 235	
	• Ribonucleic Acids 238	
<b>Chapter 12:</b>	<b>Vitamins</b>	<b>250</b>
	<b>Fat-soluble Vitamins 252</b>	
	• Vitamin A 252	
	• Vitamin D 254	
	• Vitamin E (Antisterility Vitamin, Fertility Factor) 256	
	• Vitamin K (Coagulation factor) 257	
	<b>Water-soluble Vitamins 259</b>	
	• Vitamin C (Ascorbic Acid, Antiscorbutic Vitamin) 259	
	• Vitamin B Complex 260	
	• Thiamine (Vitamin B1, Antineuritic Vitamin, Antiberiberi Factor, Aneurin) 261	

- Riboflavin (Vitamin B2, Lactoflavin) 263
- Niacin (Pellagra Preventive Factor) 264
- Pantothenic Acid 265
- Pyridoxine (Antiachrodynia Factor) 266
- Biotin 267
- Folic Acid 269
- Cyanocobalamin (Vitamin B12, Antipernicious Factor, Castle's Extrinsic Factor) 271
- Antivitamins 273**

## **Chapter 13: Acid–Base Balance 274**

- Electrolyte Composition of Plasma 274
- Mechanism 274
- Classification 279

## **Chapter 14: Water and Mineral Metabolism 282**

### **Biological Importance of Water 282**

- Dehydration 284
- Edema 285

### **Minerals 285**

#### **Iron 286**

- Functions 286

#### **Calcium 288**

- Absorption of Calcium 288
- Functions 289

#### **Sodium 290**

- Functions 290

#### **Potassium 291**

- Functions 291

#### **Phosphorus 292**

- Functions 292

#### **Sulfur 292**

#### **Copper 293**

- Functions 293

#### **Zinc 294**

- Functions 294

#### **Fluoride 294**

- Functions 294

## **Chapter 15: Xenobiotics 296**

- Metabolism of Xenobiotics 296

## **Chapter 16: Nutrition 300**

- Caloric Value of Food 300
- Respiratory Quotient (RQ) 301
- Basal Metabolic Rate 302
- Specific Dynamic Action 302

- Biological Value of Proteins 303
- Net Protein Utilization 303
- Net Dietary Protein Value 304
- Caloric Requirement 304
- Dietary Fiber 305
- Protein-Calorie Malnutrition 306
- Water as an Essential Nutrient 307
- Food Values 308
- 1,500 Calories Diabetic Diet Chart 311

## **Chapter 17: Organ Function Tests 317**

- Liver Function Tests 317
- Renal Function Tests 321
- Pancreatic Function Test 325
- Gastrointestinal Tract Function Test 328**
- D-xylose Excretion Test 328

## **Chapter 18: Immunology 329**

- Natural and Acquired Immunity 329
- Active and Passive Immunity 329
- Functions of T Cells 333**
- Effector Functions of T Cells 333
- B Cells 333
- Natural Killer Cells 335

## **Chapter 19: Cancer 345**

- Agents Causing Cancer 345

## **Chapter 20: Hormones 349**

- Hormone Action 349
- Group II (Peptide) Hormones 350
- Happiness through Hormones 353
- Insulin 354**
- Liver 354
- Muscle and Adipose Tissue 354
- Glucagon 357**
- Thyroid gland 357**
- Triiodothyronine ( $T_3$ ) and Thyroxine ( $T_4$ ) 357
- Metabolic Effects 358
- Calcitonin 358**
- Parathyroid 358
- Parathormone 358**
- Effect on Skeleton 359
- Hormones of Adrenal Medulla 359
- Hormones of the Gonads 360
- Progesterone 361
- Placental Hormones 362

- Hormones of GI Tract 362
- Anterior Pituitary Hormones 362
- Posterior Pituitary Hormones 364
- Adrenal Steroid Hormones 364
- Mineralocorticoids 365

## **Chapter 21: Protein Biosynthesis 366**

### **Activation Step 367**

### **Initiation of Polypeptide Chain (in Ribosomes) 369**

### **Elongation 371**

- Binding of the Incoming Aminoacyl-tRNA on the A-site 371
- Peptide Bond Formation 372

### **Termination 373**

- Post-translational Processing of Polypeptide Chain 374
- Inhibitors of Protein Synthesis 374

### **Codon 375**

- General Characteristic of Genetic Code 375

### **Gene 376**

### **Regulation of Gene Expression 376**

- Transcription Control 376

## **Chapter 22: Instrumentation 379**

### **Colorimetry 379**

- Lambert's Law 379
- Beer's Law 379

### **Electrophoresis 380**

### **Isotopes and their Application 381**

- Radioactivity 381

### **Electrometric Determination of pH 382**

- Hydrogen Electrode 382
- Calomel Electrode 383
- Glass Electrode 383

### **Estimation of Nitrogen Content by Micro-Kjeldahl**

### **Method 384**

- Digestion 385
- Distillation 385
- Estimation 385

### **Chromatography 386**

## **Index**

# Vitamins

## INTRODUCTION

In addition to oxygen, water, proteins, fats, carbohydrates and inorganic salts, a number of organic compounds are also necessary for the life, growth and health of animals including man. These compounds are known as the accessory dietary factors or vitamins and are only necessary in very small amount. Vitamin cannot be produced by the body and hence, must be supplied in the diet.

Vitamins are defined as organic compounds, occurring in natural food either as such or as utilizable precursors which are required in minute amounts for normal growth, maintenance and reproduction. They differ from other organic foodstuffs in that they do not enter into the tissue structure and do not undergo degradation for the purpose of providing energy. The absence of these results in deficiency disease.

Most of the vitamins are supplied by the diet. Very few vitamins which are synthesized in the intestine belongs to the vitamin B group.

Vitamins which are synthesized in the intestinal flora are: Vitamin K, thiamine, riboflavin, pyridoxine, folic acid, niacin and biotin.

But the entire requirement of these vitamins are not met by the endogenous synthesis.

Vitamin deficiencies are must often the result of consuming monotonous diet, i.e., diet-based on limited number of food sources. The requirements for vitamins are usually greatest during the neonatal period.

The vitamins have been classified into:

1. **Fat-soluble vitamins:** They are soluble in fat solvents. Vitamins in this group are vitamins A, D, E and K.
2. **Water-soluble vitamins:** They are water soluble and includes vitamin C and vitamins of B-complex.

Most of the vitamins form the integral part of coenzymes.



Fat-soluble vitamins are stored in our fat deposits (liver and adipose tissue) and water-soluble vitamins are constantly flushed from our bodies. Therefore, we can do without lipid soluble vitamins for a reasonable amount of time but we must keep replacement of the water-soluble vitamins. Vitamins acts as **coenzyme**, **antioxidants**, (free radical quenching agents) as signaling agents in the cells, as regulator of gene expression and as redox.

### Vitamin-like Compounds

Those compounds which are highlighted because of their known role as coenzymes in prokaryotes eukaryotes or roles as a probiotic (growth promoting substance) in higher animals are defined as vitamin like.

Vitamin like substances are taurine, queuosine, coenzyme Q, pteridines (other than folic acid), such as biopterin and the molybdenum containing pteridine cofactor, pyrroloquinoline quinone (PQQ).

### Vitamins as Coenzymes

<i>Vitamins</i>	<i>Active form</i>	<i>Functions performed</i>
Thiamine	Thiamine pyrophosphate	Aldehyde group transfer
Riboflavin	Flavin mononucleotide (FMN)	Hydrogen group transfer
	Flavin adenine dinucleotide (FAD)	Hydrogen group transfer
Pantothenic acid	Coenzyme A	Acyl group transfer
Nicotinamide	Nicotinamide adenine dinucleotide (NAD <sup>+</sup> )	Hydrogen transfer
	Nicotinamide adenine dinucleotide phosphate (NADP)	Hydrogen transfer
Pyridoxine	Pyridoxal phosphate	Amino group transfer
Biotin	Biocytin	Carboxyl group transfer, i.e., CO <sub>2</sub> fixing
Folic acid	Tetrahydrofolic acid, i.e., Folacin	Methyl, methylene, formyl or formimino group transfer
Cyanocobalamin	Cobamides	Alkyl group transfer
Lipoic acid	Lipoyl lysine	Acyl group transfer

## FAT-SOLUBLE VITAMINS

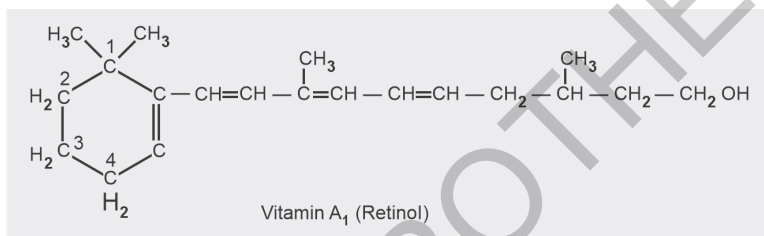
## VITAMIN A

Retinol, growth promoting vitamin, anti-infective vitamin, antixerophthalmia.

## Structure

Vitamin A occurs in two forms, vitamin A<sub>1</sub> and vitamin A<sub>2</sub>.

The structure of vitamin A<sub>1</sub> is:



Vitamin A<sub>2</sub> contains an additional double bond between C-3 and C-4.

Vitamin A<sub>2</sub> is 40 % active to vitamin A<sub>1</sub>.

Certain carotenes called provitamins are converted into vitamin A in the body.  $\beta$ -carotenes give rise to two molecules of vitamin A whereas  $\alpha$ - and  $\gamma$ -carotenes give rise to one molecule each of vitamin A.

## Functions

1. The most important function of vitamin A is in the visual cycle (page 253).

Retina contains conjugated protein rhodopsin. Rhodopsin consists of protein 'opsin' and vitamin A<sub>1</sub> aldehyde. Rhodopsin is the major light receptor of rod cells. Under the influence of light rhodopsin is converted to transretinal and opsin. Transretinal is inactive in the resynthesis of rhodopsin. Transretinal is converted to transretinal by reductase which is also inactive in rhodopsin synthesis, is passed into blood stream. During resynthesis of rhodopsin, which occurs in dim light and in the dark, active cis-retinal enters the retina from the blood and is oxidized to cis-retinal by retinal action of retinal reductase. Now cis-retinal couples with opsin to form rhodopsin. The visual process involves

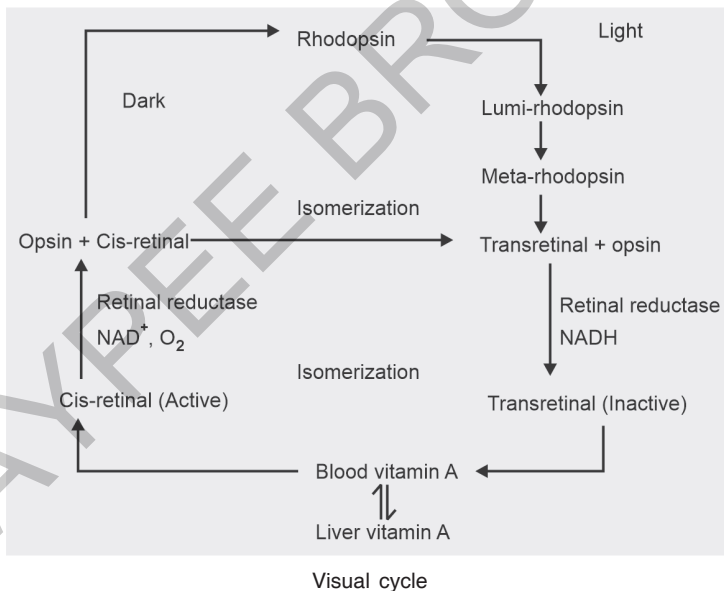
the removal of active retinal isomer from the blood by the retina which returns the inactive isomer to the circulation.

2. In the maintenance of proper health of epithelium tissues.
3. For the stability and integrity of cellular and subcellular membranes.
4. Necessary for the synthesis of mucopolysaccharides as it helps in the incorporation of sulfur in chondroitin sulfate.
5. It is also involved in the nucleic acid metabolism.
6. It is also involved in the electron transport chain and in oxidative phosphorylation.

### Sources

*Provitamin sources:* Food rich in carotenoid such as carrot, papayas, tomatoes, etc.

*Readymade or preformed sources:* Fish liver oils such as shark, cod, halibut fish, egg yolk, butter, milk products.



*Daily requirement:*

5,000 IU

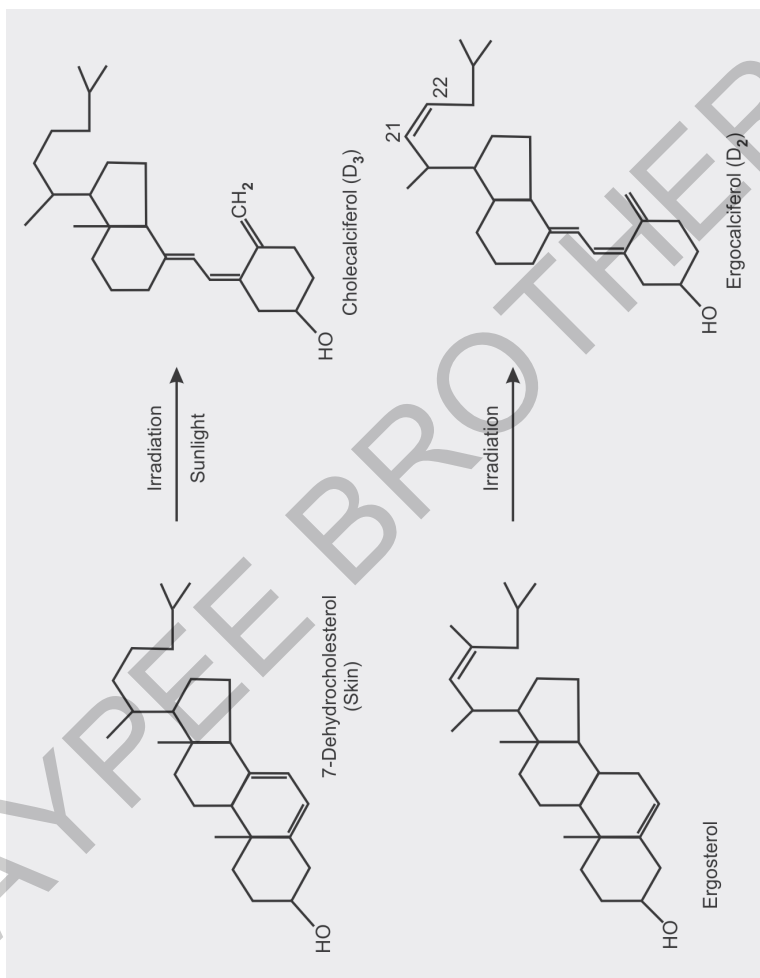
### Deficiency Disease

Deficiency of vitamin A gives rise to night blindness.

## Hypervitaminosis A

Excessive intake of vitamin A gives rise to hypervitaminosis A.

The symptom of this toxicity include anorexia, irritability, headache, peeling of skin, vomiting.



## VITAMIN D

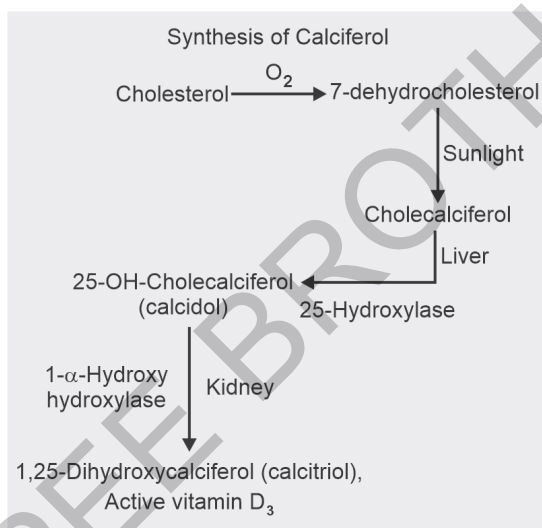
The term vitamin D does not refer to a single dietary factor but to a number of chemically related compounds, all of which have the

property of preventing or curing rickets. The two most active substances in this respect are vitamin  $D_2$  and vitamin  $D_3$ .

## Structure

Vitamin  $D_2$  is also known as ergocalciferol and vitamin  $D_3$  as cholecalciferol.

Irradiation of 7-dehydrocholesterol with ultraviolet radiations produces cholecalciferol whereas irradiation of ergosterol produces ergocalciferol.



Vitamin  $D_2$  differs from vitamin  $D_3$  with respect to the double bond additionally present in the side chain at position 20 and 21.

The biologically active form of vitamin D are 25-hydroxy-cholecalciferol (25-HCC) and 1,25-cholecalciferol.

Liver converts cholecalciferol to 25-HCC, whereas kidney converts 25-HCC to 1,25 dihydroxycholecalciferol (1,25-DHCC).

Another important active form formed by the kidney is 24,25-dihydroxycholecalciferol (24,25-DHCC) but very little is known of biological function of this form.

1,25-DHCC perform the following functions:

1. It promotes calcium absorption from the intestine.
2. It promotes mobilization of calcium from bones.

### Functions

1. The basic action of vitamin D is to increase the absorption of calcium and phosphorus from the intestines.
2. Vitamin D promotes resorption of bone and mobilization of calcium from bones.
3. Vitamin D increases excretion of phosphate by the kidney.

### Sources

Fish liver oils (i.e., cod, shark, halibut), egg yolk, milk, etc.

### Daily requirement

- 400 IU infants and children
- 100 IU adults
- 400 IU pregnancy and lactation

### Deficiency Disease

Deficiency of vitamin D gives rise to rickets in children and osteomalacia in adults.

In rickets, there is a fall in intestinal absorption of calcium and phosphate, increased excretion of urinary phosphate and loss of calcium from the bones, leading to softness and deformities of bones.

In rickets and osteomalacia, there is an increase in serum alkaline phosphatase activity.

### Hypervitaminosis D

Doses above 1,500 units per day for long period give rise to vitamin D toxicity.

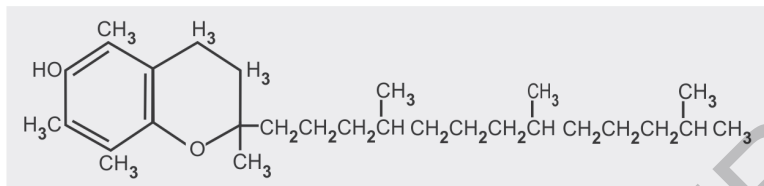
Excessive intake of vitamin D causes loss of appetite, nausea, irritability, excessive mobilization of calcium from bones into blood.

### VITAMIN E (ANTISTERILITY VITAMIN, FERTILITY FACTOR)

Vitamin E refers to a group of compounds having vitamin E activity and are known as tocopherols. Four unsaturated alcohols, i.e.,  $\alpha$ -,  $\beta$ -,  $\gamma$ -, and  $\delta$ -tocopherols occur in nature. These tocopherols differ slightly in structure in their side chain,  $\alpha$ -tocopherol is most potent of them.

## Structure

The structure of  $\alpha$ -tocopherol is:



They are thermostable and sensitive to the effects of oxidizing agents and ultraviolet rays.

## Functions

1. Tocopherols act as powerful antioxidants:
  - a. They prevent the autoxidation of vitamin A and carotenes.
  - b. They prevent the formation of fatty acid peroxidases in tissues due to the autoxidation of unsaturated fatty acids with oxygen.
  - c. They protect the lipids of biological membranes against oxygen by acting as antioxidants (i.e., prevent the pero-oxidation of polyunsaturated fatty acids that occur in membranes throughout the body).
2. Vitamin E prevents rancidity.

## Sources

Wheat germ oil, corn oil, peanut oil, soyabean oil, sunflower oil, egg yolk, leaves of spinach, alfalfa, sweet potatoes.

*Daily Requirement 15 IU*

Vitamin E intake is related to the intake of polyunsaturated fatty acids, i.e., 0.4 mg/g of polyunsaturated fatty acids.

## Deficiency Disease

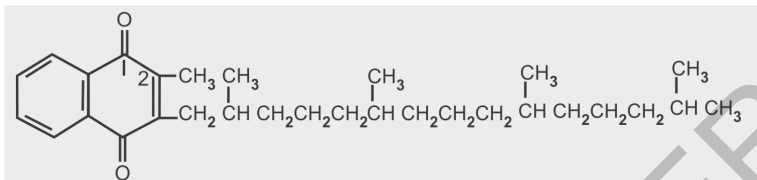
Deficiency of vitamin E gives rise to sterility in rats.

## VITAMIN K (COAGULATION FACTOR)

Two naturally occurring vitamin K are vitamin K1 and vitamin K2. Both are naphthaquinone derivatives.

## Structure

Vitamin K1 is phyloquinone and is chemically known as 2-methyl-3-phytyl-1,4-naphthoquinone.



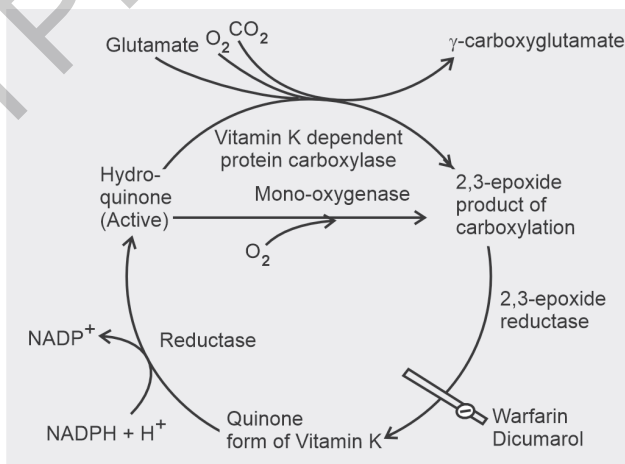
Vitamin K2 is farnesoquinone and is chemically known as 2-methyl-3-difarnesyl-1,4-naphthoquinone.

Vitamin K is thermostable can withstand reduction and is rapidly oxidized both in acidic and alkaline medium. It is completely destroyed by ultraviolet radiations.

Certain compounds having vitamin K activity are called vitamines. Vitamines are synthetic compounds possessing vitamin K activity (*Example*: Menadione). Menadione is more potent than vitamin K1 on weight basis.

## Functions

1. In the synthesis of prothrombin.
2. It is involved in oxidative processes taking place in photosynthesis of plant kingdom.
3. It is involved in electron transport chain and is involved in oxidative phosphorylation.



Vitamin K cycle



## Sources

Vitamin K<sub>1</sub> is present in alfalfa, spinach, cabbage, cauliflower, egg yolk, liver.

Vitamin K<sub>2</sub> is present in putrifying fish. It is also synthesized by intestinal flora.

## Daily Requirement

Sufficient amounts of vitamin K are synthesized by intestinal bacteria so there is no dietary requirement under physiological condition.

## Deficiency Disease

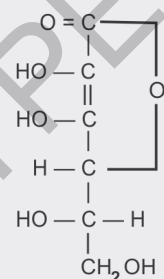
Vitamin K deficiency gives rise to hypoprothrombinemia which leads to prolongation of prothrombin time.

## WATER-SOLUBLE VITAMINS

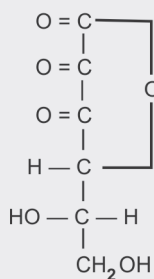
Water-soluble vitamins includes vitamin C and members of vitamin B complex.

## VITAMIN C (ASCORBIC ACID, ANTISCORBUTIC VITAMIN)

### Structure



L-ascorbic acid



L-dehydroascorbic acid

Vitamin C, which is hydrophilic, acts as an antioxidant in solution.

Vitamin C is a powerful reducing agent and is oxidized to dehydroascorbic acid. Both forms are biologically active. It is stable in acidic solution at low temperatures but undergoes destruction in alkaline solution when in contact with air.

Vitamin C is not synthesized by man and its entire requirement is met by diet.

The most rich sources of vitamin C in the body are adrenal cortex, corpus luteum, pituitary, pancreas, liver, etc.

### Functions

1. Participation in the hydroxylation of proline and lysine present in collagen, an intracellular cementing substance.
2. Participates in the synthesis of steroid hormones both in adrenal cortex and corpus luteum.
3. Participates as cofactor in the following reaction:
  - a. In phenylalanine metabolism.  
p-hydroxyphenylpyruvic acid  $\rightarrow$  homogentisic acid
  - b. Dopamine  $\rightarrow$  Norepinephrine
  - c. Folic acid  $\rightarrow$  Folinic acid.
4. Vitamin C is necessary for the synthesis of carnitine in the liver.
5. Necessary for the absorption of iron by reducing ferric form to ferrous form.
6. In tissue respiration, i.e., oxidation-reduction phenomenon.
7. In bile acid formation, vitamin C is required at the 7- $\alpha$ -hydroxylase step.
8. Ascorbic acid may act as water-soluble antioxidant and inhibit the formation of nitrosamine.

### Sources

Citrus fruits such as lemon, orange, pineapple, etc. Indian gooseberry, green pepper, cauliflower, tomatoes, spinach, potato.

*Daily requirement:* 60–80 mg.

### Deficiency Disease

Deficiency of vitamin C gives rise to scurvy. The early manifestation in man are swelling of joints, hemorrhage in skin, muscle, gastrointestinal tract, inflammation of gums, ulceration, etc. In scurvy, vitamin C level in blood falls down.

### VITAMIN B COMPLEX

The members of this group are:

1. Thiamine (B1).
2. Riboflavin (B2).

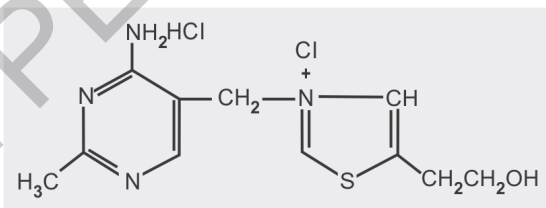
3. Pantothenic acid (B3).
4. Choline (B4).
5. Niacin (B5).
6. Pyridoxine (B6).
7. Biotin (B7).
8. Folic acid (B9).
9. Cyanocobalamin (B12).
10. Para aminobenzoic acid.
11. Inositol.
12. Lipoic acid.

The vitamins of this family have been grouped together because of the following fulfillment:

1. Usually present in yeast.
  2. Present in the outer covering of seeds and cereals.
  3. Synthesized by the microorganisms in the intestines.
  4. They are water soluble.
  5. Required in minute amounts and their deficiencies give rise to ordinary manifestations.
  6. They usually serve as a coenzyme of various enzyme systems.
- Foods that are poor sources of one of the B vitamins level to be the poor sources of several B vitamins.

### THIAMINE (VITAMIN B1, ANTINEURITIC VITAMIN, ANTIBERIBERI FACTOR, ANEURIN)

#### Structure



Thiamine consists of a substituted pyrimidine ring joined by a methylene bridge to substituted thiazole ring.

Thiamine is water soluble. It is thermolabile, destroyed in alkaline medium but thermostable in acidic medium.

Thiamine occurs in the cells largely as its active coenzyme form, i.e., thiamine pyrophosphate, also called cocarboxylase.

# BIOCHEMISTRY FOR STUDENTS

*Biochemistry for Students* serves as a quick reading material for students. The present 14th edition has been thoroughly revised and updated, and it is very popular among the students, medical practitioners, and the related community.

The primary aim of this book is to meet the needs of all students of health sciences in knowing the important applied aspects of various topics in biochemistry and from examination point of view. Important points are presented in tables and figures to facilitate students to grasp the matter effectively.

**VK Malhotra** PhD(Gold Medalist) had an Exchequer career in his student days with a Gold Medal in Medical Biochemistry from Maulana Azad Medical College (MAMC), New Delhi, India. He has more than 35 years of experience in teaching students of medical, dental, nursing, and allied sciences. He is an eminent scholar and has a vast teaching experience.

Printed in India

Available at all medical bookstores  
or buy online at [www.jaypeebrothers.com](http://www.jaypeebrothers.com)



**JAYPEE BROTHERS**  
**Medical Publishers (P) Ltd.**  
EMCA House, 23/23-B, Ansari Road,  
Daryaganj, New Delhi - 110 002, INDIA  
[www.jaypeebrothers.com](http://www.jaypeebrothers.com)

Join us on [f facebook.com/JaypeeMedicalPublishers](https://www.facebook.com/JaypeeMedicalPublishers)

Shelving Recommendation  
**BIOCHEMISTRY**

