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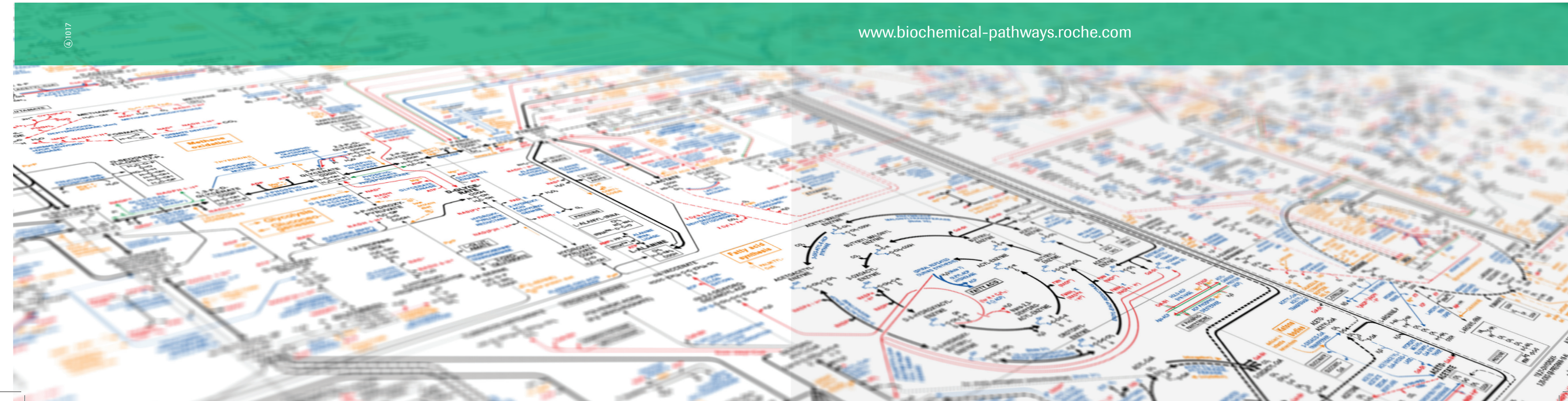
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# Biochemical Pathways

*4<sup>th</sup> Edition - Index*

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## Preface

The fourth edition marks the 40th anniversary of the "Biochemical Pathways" wall chart.

The first edition was published in 1965 and showed a compilation of the most central pathways of metabolism, such as glycolysis, citric acid cycle, synthesis and degradation of fatty acids, amino acids and nucleotides. This chart was well received. Many requests were made to expand it to other fields of biochemistry. This was taken into account by including into the second edition 1972 more details of these pathways as well as showing steroids, tetrapyrrole compounds and the basics of oxidative phosphorylation and protein synthesis. Most important, however, was the inclusion of regulation mechanisms, demonstrating the mutual interdependency of the members of the metabolic network.

The following years brought an enormous increase of biochemical knowledge. The third edition of the wall chart came out in 1992. Many new fields had to be incorporated into it. It became necessary to greatly enlarge the wall chart and divide it into 2 parts. In part 1, a revised selection of the "classical" biochemical reactions was shown. The substrates and products of these reactions are usually of low molecular weight and therefore the usual chemical formulas were adequate for demonstration. This did not hold for the newer aspects of biochemistry, which were the contents of part 2. The largest addition was the representation of DNA replication, the transcription and the translation mechanisms. Since large nucleic acid / protein complexes are involved in these reactions, different graphical methods had to be applied. This was also true for surface phenomena, such as the passage of molecules through membranes, as well as the signal transduction through them. Frequently, these signals are passed on via a cascade of reactions to their site of action, e.g., for expression of genes in the nucleus. In order to take this into account, in part 2 the cell and its organelles were shown in a schematic way and the reactions were arranged accordingly. Since many functions are different in prokaryotes and eukaryotes, the respective graphs had to be separated. Additionally, the mechanisms of the respiratory chain, photosynthesis and special microbial metabolism, especially with regard to the redox potentials were shown. Due to their importance in medicine, blood coagulation reactions, as well as the immunology and complement systems were included.

This work was performed with the help of many scientists. Without their assistance, a presentation of such a wide range of topics would not have been possible. I am grateful to them, either for their contribution to the contents or for checking the accuracy: Dr. Baron, Dr. Barz, Professor Dr. Böck, Dr. Bumann, Dr. Burtscher, Dr. Dony, Dr. Felber, Dr. Grossmann, Dr. Haselbeck, Dr. Heider, Dr. Hösel, Dr. Kehrel, Professor Dr. Klingenberg, Professor Dr. Kresse, Dr. Lill, Dr. Marwan, Professor Dr. Oesterhelt, Dr. Ofenloch, Professor Dr. Rieber, Professor Dr. Widdel.

In the years after the third edition, again much scientific progress took place. When considering the fourth edition, a decision had to be made regarding the material to be included. Although this problem always existed (see below), the question of selection became still more pressing. A wall chart should not surpass a certain size in order to be easily handled and to yield a general overview. I feel that this limit has been

reached by the present size of almost 2 ½ square meters (26 square foot). Thus it was decided that the new edition should show a limited updating of the topics and not a considerable expansion of its contents.

If a more detailed coverage of biochemistry in a similar style of representation is desired, the user is referred to the book "Biochemical Pathways". The graphs contain a greatly expanded range of information and are supplemented by explanatory texts. The book was compiled by essentially the same team as the wall chart and edited by myself. The English edition was published by John Wiley & Sons, New York etc. (ISBN 0-471-33130-9), the German edition by Spektrum Akademischer Verlag Heidelberg etc. (ISBN 3-86025-239-9, presently out of print).

## General Aspects

In the wall chart "Biochemical Pathways" the following principles were applied:

a) There are many more pathways known than can be shown on a reasonably sized chart. Instead of concentrating on a single organism or organ, we chose to give a cross-section of general metabolism in various species and organs. This required at least some indication of occurrence of these reactions, as has been done by the color of the reaction arrows or special naming at segments of the cell membrane.

The selection of reactions has to be made arbitrarily. Of course, no discussion is necessary about e. g. glycolysis, protein biosynthesis and other central reactions. Peripheral reaction pathways are preferably selected if they are of high interest in biochemical, medical or biological research (receptors, vitamins, antibiotics, compounds of importance in regulation etc.), if they are of interest in medicine (e. g. blood coagulation, complement system), if they lead to important end products (e. g. microbiological fermentations) or if they enable comparison of phylogenetic development (anaerobic/aerobic respiration or photosynthesis in various species).

Some indication on the degree of selection can be taken from the fact that in the present "Pathways" about 1000 enzymes are shown, while the 1984 "Enzyme Nomenclature" with its 2 supplements names 2859 enzymes. Estimations of the number of proteins (with and without enzymatic activity) in a single mammalian cell are in the order of magnitude of 30000.

b) Whenever possible, the names of enzymes and substrates given in the "Enzyme Nomenclature 1984" (Academic Press, Orlando etc. 1984) and both supplements 1986 and 1989 [ *Eur.J.Biochem.* 157, 1-26 (1988) and 179, 489-533 (1989)] have been used. Recently, abbreviations derived from gene symbols for proteins with enzymatic activity are used more frequently. They do not indicate the catalyzed reaction.

c) When chemical formulas are used, the conversion of the compounds with time is given by the direction of the reaction arrow. However, when structural arrangements are shown, movement of molecules and reaction progress with time have to be shown by the same two-dimensional representation. Whenever actual movements play the predominant role (e. g. H<sup>+</sup> in the membranes in the respiratory chain or during photosynthesis), the "fixed" components (e. g. chlorophylls, FeS centers) are shown only once. When different states of components are

the most important facts (e. g. G-protein dependent receptors, receptors with tyrosine kinase activity), the different states are shown next to each other. Although this is not fully consistent, it still appears to be the simplest form of representation.

d) Although most biochemical reactions are reversible, most of them proceed *in vivo* preferably in one direction, depending on the supply of reaction partners, removal of reaction products and the equilibrium constant. Thus, the classical subdivision of "anabolic" and "catabolic" pathways is shown in the chart by solid and by dashed arrows. If the actual equilibrium in the biological system is far on one side, it is indicated with an additional orange arrow. "Amphibolic" pathways, which are passed through in either direction under biological conditions, are shown here like anabolic pathways, since further symbols would not improve legibility.

e) In general, we desisted from showing detailed reaction mechanisms. Only in cases where discrete steps (e. g. in multi-enzyme systems) are involved or well-characterized intermediates exist, single steps are given. The same holds true for receptor-activation steps etc.

f) The interrelationships of metabolic pathways cause the biggest technical problem of graphical representation. Since many compounds take part in various pathways, one would obtain a "spider web" of lines criss-crossing the whole chart. In order to avoid this, one has to "cut" connections. The respective compounds, which reoccur in other places of the chart, are written here in sharp-edged boxes.

g) On the other hand, in part 2, symbols for proteins have to be used. We chose round- edged boxes for them. Both kinds of boxes, therefore, have to be considered differently. If, e. g. by phosphorylation, structural and functional modifications occur, the shape of the boxes changes.

h) The lipid bilayers of membranes (cell surface and cell organelles) have approximately the same thickness. However, graphical reasons require drawing them in different widths, depending on the details of the membranes to be shown. Otherwise, much space would be wasted on little information.

i) For regulation of reaction velocity, two major systems are effective: the "quick" regulation by changing the activity of enzymes, e. g. by "allosteric" (Monod) or "cooperative" (Koshland) mechanisms and the "slow" regulation by synthesis or degradation of the respective enzymes. These are shown in the chart by full or by dashed arrows, respectively, pointing from the effector compound to the regulated reaction.  $\oplus$  and  $\ominus$  signs indicate activation or inhibition. The regulation usually has its point of attack on the first enzyme of a metabolic chain, but (at least in the "slow" regulation) the following enzymes are often affected in the same way. This, however, is not always mentioned specifically in the literature and therefore not shown here.

j) References are not included in this chart. The editor feels that there is no absolute need for this work, since the "Enzyme Nomenclature" (see above), the "Annual Reviews of Biochemistry" (Annual Reviews Inc. , Palo Alto) and other review series, textbooks etc. give a wealth of information. It is beyond the scope of this chart to present complete references. Increased usefulness, however, might be drawn from the index. It should help to find a compound or reaction quickly.

I do hope that the new edition of the wall chart will again prove useful to its users.

Tutzing, October 31, 2005

Gerhard Michal

The decimal classification refers to the "Enzyme Nomenclature, Recommendations (1984)" (Academic Press, Orlando etc. 1984) and its supplements (Eur.J.Biochem. 157,1 (1986) and 179,489 (1989)). Enzymes named below without classification numbers are not listed there. Instead of "transaminase", "amino-transferase" is frequently used.

<b>A</b>	Acetylcholinesterase 3.1.1.7 A8, B8, V4	Aconitase [see aconitate hydratase] 4.2.1.3 F6	Adenosine 5'-diphosphate [ADP] H2 + others
A gene product [blood groups] R2	6-S-Acetyldihydroliipoate F5	<i>cis</i> -Aconitate F6	Adenosine 5'-phosphate [AMP] G2 + others
A specificity [blood groups] S2	N-Acetylgalactosaminyl-glycopeptide galactosyltransferase R4	Aconitate decarboxylase 4.1.1.6 F6	Adenosine 5'-triphosphate [ATP] H2 + others
A-3,5-MP responsive element binding protein [CREB] P7, U4	$\beta$ -Acetylglucosamine D3	Aconitate hydratase 4.1.2.3 F6	Adenosine deaminase 3.5.4.4 G1
Acetaldehyde A8, B8, E6, H4	N-Acetylglucosamine kinase 2.7.1.59 D4	Acryloyl-CoA J4	Adenosine kinase 2.7.1.20 G2
Acetate C4, D4, F6, F7, G7, H6, I6	N-Acetylglucosamine-1-phosphodiester N-acetylglucosaminidase 3.1.4.45 S3	ACTH receptor V3	Adenosine phosphosulfate [APS] M10, N10
Acetate kinase 2.7.2.1 C4	N-Acetylglucosaminidase 3.2.1.50 D4	Actin R3, U5	Adenosine triphosphatase [ATPase] 3.6.1.3 H1, H2
Acetate-CoA ligase 6.2.1.1 J4	N-Acetylglucosaminyl transferase R4	Actinomycin D M8, Q6, R6, S6	Adenosine-phosphate deaminase 3.5.4.17 G2
2-Aceto-2-hydroxybutyrate A9	N-Acetylglucosaminylidiphosphodolichol N-acetylglucosaminyltransferase 2.4.1.141 R5	110 kD Activator, 110 kD proactivator U2	S-Adenosyl-L-homocysteine H3 + others
Acetoacetate, F8, H3, L4	$\beta$ -N-Acetylglucosaminylglycopeptide $\beta$ -1, 4-galactosyltransferase 2.4.1.38 R3	Actomyosin [myosin ATPase] 3.6.1.32 U4, U5	S-Adenosyl-L-methionine H3 + others
Acetoacetate decarboxylase 4.1.1.4 F8, L3	N-Acetylglutamate G7	Acyl carrier protein [ACP] F8	Adenylylhomocysteinase 3.3.1.1 H3
Acetoacetyl-CoA F8	N-Acetylglutamate kinase 2.7.2.8 G7	Acyl enzyme E7	Adenylylate cyclase 4.6.1.1 A6, U3
Acetoacetyl-CoA hydrolase 3.1.2.11 F8	N-Acetylglutamate phosphate G7	[Acyl-carrier-protein] acetyltransferase 2.3.1.38 F7	Adenylylate kinase 2.7.4.3 G7
Acetoacetyl-CoA: acetate CoA transferase L4	N-Acetylglutamate semialdehyde G7	[Acyl-carrier-protein] malonyltransferase 2.3.1.39 E7	Adenylosuccinate G2
Acetoacetyl-enzyme E7	N-Acetylglutamate kinase 2.7.2.8 G7	[Acyl-carrier-protein] phosphodiesterase 3.1.4.14 F8	Adenylosuccinate lyase 4.3.2.2 F2, G2
( <i>R</i> )-Acetoin A10	N-Acetylglutamate phosphate G7	Acyl-CoA C7, C8, D7, E8	Adenylosuccinate synthase 6.3.4.4 G2
2-Acetolactate A10	N-Acetylglutamate semialdehyde G7	Acyl-CoA acyltransferase 2.3.1.16 E8	Adenylyl sulfatase 3.6.2.1 J4
Acetolactate decarboxylase 4.1.1.5 A10, F8	N-Acetylglutamate semialdehyde G7	Acyl-CoA dehydrogenase 1.3.99.3 B9, B10, E8, J4	Adenylyl sulfate [APS] J4
Acetolactate synthase 4.1.3.18 A9, A10	N-Acetylglutamate semialdehyde G7	Acyl-CoA ligases 6.2.1.x D8	Adenylylsulfate kinase 2.7.1.25 J4
Acetone E8	N-Acetylglutamate semialdehyde G7	Acyl-lysine deacylase 3.5.12.17 K3	Adenylylsulfate reductase 1.8.99.2 J4, M9, M10, N9
Acetyl enzyme F7	N-Acetylglutamate semialdehyde G7	Acyladenylate D8	ADP-D-glucose B6, V9
N-Acetyl- $\gamma$ -glutamyl-phosphate reductase 1.2.1.38 G7	N-Acetylglutamate semialdehyde G7	Acylcarnitine E8	ADP/ATP carrier Q9
Acetyl-CoA A9, C4, C9, F5, G3, G5, G7, H4, L4	N-Acetylglutamate semialdehyde G7	N-Acylglucosamine 2-epimerase 5.1.3.8 D4	ADPribose O3
Acetyl-CoA acetyltransferase [thiolase] 2.3.1.9 F8, L4	N-Acetylglutamate semialdehyde G7	Acylglycerol 3-phosphate D7	Adrenaline [see epinephrine] V3
Acetyl-CoA acyltransferase 2.3.1.16 C9, E9, L4	N-Acetylglutamate semialdehyde G7	Acylglycerol kinase 2.7.1.94 D8	$\alpha_2$ -Adrenergic receptor V3
Acetyl-CoA carboxylase 6.4.1.2 F7	N-Acetylglutamate semialdehyde G7	Acylglycerol palmitoyl [acyl-] transferase 2.3.1.22 D8	$\beta$ -Adrenergic receptor V3
[Acetyl-CoA carboxylase] phosphatase 3.1.3.4 F6	N-Acetylglutamate semialdehyde G7	1-Acylglycerol-3-phosphate acyltransferase 2.3.1.51 D7	$\beta$ -Adrenergic receptor kinase 2.7.1.126 V3
Acetyl-CoA ligase 6.2.1.1 F6	N-Acetylglutamate semialdehyde G7	N-Acylmannosamine kinase 2.7.1.60 E4	Adrenodoxin H9, H10, I9, I10, J9, K10
N-Acetyl-D-glucosamine D4	N-Acetylglutamate semialdehyde G7	N-Acylneuraminat-9-phosphate synthase 4.1.3.20 E3	Adrenosterone J9
N-Acetyl-D-glucosamine 1-phosphate D4	N-Acetylglutamate semialdehyde G7	Acylsphingosine deacylase 3.5.1.23 C8	Adriamycin M8
N-Acetyl-D-glucosamine 6-phosphate D4	N-Acetylglutamate semialdehyde G7	Adenine H1, I1, O4	Agmatinase 3.5.3.11 F7
N-Acetyl-D-mannosamine E4	N-Acetylglutamate semialdehyde G7	Adenine deaminase 3.5.4.2 G1	Agmatine F7
N-Acetyl-D-mannosamine 6-phosphate E3	N-Acetylglutamate semialdehyde G7	Adenine phosphoribosyltransferase 2.4.2.7 G2	D-Alanine F4, N3
N <sup>6</sup> -Acetyl-L-lysine K3	N-Acetylglutamate semialdehyde G7	Adenosine G1, H3, K7	L-Alanine B7, E6, F4, G6, I7, J2, N3
N <sup>6</sup> -Acetyl- $\beta$ -L-lysine transaminase 2.6.1.65 K3	N-Acetylglutamate semialdehyde G7	Adenosyl cobinamide I6	$\beta$ -Alanine B10, G4, K8
Acetyladenylate F6	N-Acetylglutamate semialdehyde G7	Adenosine 3',5'-diphosphate [PAP] I4, K4	Alanine dehydrogenase 1.4.1.1 E6
(-) O-Acetylcarnitine F6	N-Acetylglutamate semialdehyde G7	Adenosine 3',5'-monophosphate (cyclic) [A-3, 5-PMP; cAMP] A6, M6, U3	Alanine racemase 5.1.1.1 F4, N3
O-Acetylcholine B8, V3, V4	N-Acetylglutamate semialdehyde G7		Alanine transaminase [ALT] 2.6.1.2 E6
	N-Acetylglutamate semialdehyde G7		$\beta$ -Alanine-(3-aminoisobutyrate)-pyruvate transaminase C10



Squares A...L refer to part 1, squares M...V to part 2.

D-Alanine-D-Alanine N3  
D-Alanine-D-Alanine ligase 6.3.2.4 N3  
Alanine-glyoxylate transaminase 2.6.1.44 B7, G5  
Alanine-oxo-acid transaminase 2.6.1.12 D6  
β-Alanine-pyruvate transaminase 2.6.1.18 F4, K10, L10  
Alanine-tRNA ligase 6.1.1.7 E6  
L-Alanyl-tRNA E6  
1-Alcohol D8  
Alcohol dehydrogenase 1.1.1.1 D8, E6, J10  
Alcohol dehydrogenase (acceptor) 1.1.99.8 D5  
Alcohol sulfotransferase 2.8.2.2 I10, K4  
Aldehyde D8  
Aldehyde dehydrogenase (NAD<sup>+</sup>) 1.2.1.3 A2, D6, D8, E6, H2, I2, J10  
Aldehyde dehydrogenase (PQQ) 1.2.99.3 D8  
Aldehyde oxidase 1.2.3.1 F2  
Aldehyde reductase 1.1.1.21 C3, C6  
Aldosterone G9  
Aldosterone hemiacetal F9  
Alkaloids G2  
Alkane D8  
Alkane1-monooxygenase 1.14.15.3 D8  
Allantoate H2  
Allantoicase 3.5.3.4 H1  
Allantoin H1  
Allantoinase 3.5.2.5 H1  
Allolactose N6  
Alternative complement pathway C3/C5 convertase 2.4.21.47 R1  
α-Amanitin Q6, R6, R7, S6  
ω-Amidase 3.5.1.3 F5, G5  
Amidophosphoribosyltransferase 2.4.2.14 D2  
Amine oxidase (copper-containing) 1.4.3.6 F2, F7  
Amine oxidase (flavin-containing) 1.4.3.4 I2  
Amino sugars D4  
2-Amino-3-carboxymuconate semialdehyde K2  
2-Amino-3-oxoadipate H5  
2-Amino-4-hydroxy-6-(D-erythro-1, 2, 3-trihydroxypropyl)-dihydropteridine triphosphate L1  
2-Amino-4-hydroxy-6-(D-erythro-trihydroxypropyl)-dihydropteridine [dihydro-neopterin] L1  
2-Amino-4-hydroxy-6-hydroxymethyl-7, 8-dihydropteridine L1  
2-Amino-4-hydroxy-6-hydroxymethyl-7, 8-dihydropteridine pyrophosphate L1  
2-Amino-4-hydroxy-6-hydroxymethyl-7, 8-dihydropteridine pyrophosphokinase 2.7.6.3 L1  
5-Amino-4-imidazole-carboxylate H1  
Amino-acid acetyltransferase 2.3.1.1 G7  
D-Amino-acid oxidase 1.4.3.3 B7, G6, H8, I8  
L-Amino-acid oxidase 1.4.3.2 B9, H2  
L-2-Aminoacetate H5  
Aminoacetone H5  
Aminoacyl-phosphatidylglycerol D7  
Aminoacyl-tRNA ligases 6.1.1.x N4, Q5  
Aminoacyl-tRNA<sup>aa</sup> [unspecified] N4, Q4  
L-2-Amino adipate , J3, L3  
2-Amino adipate reductase J3  
2-Amino adipate semialdehyde J3  
2-Amino adipate transaminase 2.6.1.39 I3  
L-Amino adipate-semialdehyde dehydrogenase 1.2.1.31 J3  
L, L, D-Amino adipyl-cysteyl-valine synthase K3  
ε-(D-2-Amino adipyl-L-cysteiny)-L-valine K3  
4-Aminobenzoate E3, L2  
4-Aminobutyraldehyde F7  
Aminobutyraldehyde dehydrogenase 1.2.1.19 F7, H6  
4-Aminobutyrate H6  
γ-Aminobutyrate receptor V4  
4-Aminobutyrate transaminase 2.6.1.19 F4, H6  
Aminocarboxymuconate-semialdehyde decarboxylase 4.1.1.45 K2  
Aminodeoxygluconate dehydratase 4.2.1.26 C4  
Aminoimidazolase 3.5.4.8 H2  
Aminoimidazole H1  
(S)-3-Aminoisobutyrate C10, L8  
5-Aminolevulinat H5  
5-Aminolevulinat synthase 2.3.1.37 G5, H5  
5-Aminomethyl dihydrolipoyl protein B7  
Aminomethyltransferase 2.1.2.10 A7, B7  
2-Aminomuconate K1  
2-Aminomuconate semialdehyde K2  
2-Aminomuconate-semialdehyde dehydrogenase 1.2.1.32 K2  
6-Aminopenicillinate L4  
4-(Aminophenyl)-1, 2, 3, 4-tetrahydroxypentane K2  
1-Aminopropan-2-ol H5  
(R)-Aminopropan-2-ol dehydrogenase 1.1.1.75 H5  
5-Aminovalerate H8  
Ammonia G8, M10, N10  
Ammonia monooxygenase N10  
AMP nucleosidase 3.2.2.4 G1  
Amplification loop [complement system] QR1  
α-Amylase 3.2.1.1 A6  
β-Amylase 3.2.1.2 A6  
Amylopectin A5  
Amylose A5  
Anaerobic respiration M9, M10  
Anaplerotic reactions F5  
Androgen receptor U6  
Androgens J10  
Androst-4-ene-3, 17-dione I9  
5α-Androstane-3, 17-dione L9  
5β-Androstane-3, 17-dione L10  
Androsterone L9  
Anion channel RS3  
Ankyrin R3  
Anthranilate E3, J2  
Anthranilate dioxygenase (deaminating, decarboxylating) 1.14.12.1 E3  
Anthranilate phosphoribosyltransferase 2.4.2.18 F3  
Anthranilate synthase 4.1.3.27 E3  
Antigen-presenting cell PQ2  
Antimycin A P9, S10  
α<sub>2</sub>-Antiplasmin [α<sub>2</sub>-AP] U2, V1  
Antithrombin III [AT III] TUV1, V2  
Aphidicolin S7  
Apocytochrome c K5  
Apo ferritin K5  
Apolipoprotein B-100 S2  
Apolipoprotein C S3  
Apyrase 3.6.1.5 G2, H2  
L-Arabinitol dehydrogenase 1.1.1.12 C3  
L-Arabinose C3  
L-Arabinose isomerase 5.3.1.4 C3  
L-Arabitol dehydrogenase (ribulose-forming) C3  
L-Arabitol [L-arabinitol] C3  
Arachidonate T6  
Arachidonate derived hormones [eicosanoids] TU6, TU7  
Arbutin A3  
Arginase 3.5.3.1 F8  
L-Arginine F8  
Arginine 2-monooxygenase 1.13.12.1 F8  
Arginine decarboxylase 4.1.1.19 F8  
Arginine deiminase 3.5.3.6 G8  
Arginine kinase 2.7.3.3 F8  
L-Arginine phosphate F8  
L-Arginine-tRNA ligase 6.1.1.19 F8  
L-Argininosuccinate G8  
Argininosuccinate lyase 4.3.2.1 F8  
Argininosuccinate synthase 6.3.4.5 G8  
L-Arginyl-tRNA F8  
Aromatic amino acids D3...H3  
Aromatic-L-amino acid decarboxylase 4.1.1.28 G2, I2  
Arrestin V4  
ARS sequence [of yeast] R8  
Aryl sulfotransferase 2.8.2.1 K4  
Arylamine sulfotransferase 2.8.2.3 K4  
Arylsulfatase 3.1.6.1 K4, K9  
Arylsulfotransferase 2.8.2.1 K4  
L-erythro-Ascorbate C2  
Ascorbate 2, 3-dioxygenase 1.13.11.13 C2  
L-Ascorbate oxidase 1.10.3.3 B2  
L-Ascorbate [vitamin C] B2, G2, I7  
Asparaginase 3.5.1.1 F4  
L-Asparagine F4  
Asparagine-oxo-acid transaminase 2.6.1.14 F4  
Aspartate kinase 2.7.2.4 F4  
Aspartate transaminase [AST] 2.6.1.1 F5  
L-Aspartate F4, G8, J2  
Aspartate 1-decarboxylase 4.1.1.11 F4  
Aspartate 4-decarboxylase 4.1.1.12 F4  
Aspartate carbamoyltransferase 2.1.3.2 G8  
Aspartate group of amino acids FG4  
L-Aspartate semialdehyde G4  
Aspartate-ammonia ligase 6.3.1.1 F4  
Aspartate-semialdehyde dehydrogenase 1.2.1.11 G4  
4-Aspartyl phosphate G4  
ATP citrate (*pro-3S*)-lyase 4.1.3.8 F6  
ATP phosphoribosyltransferase 2.4.2.17 D2  
ATPases 3.6.1.x H1, H2  
Atractiloside Q9  
Atrial natriuretic factor [ANF] V5  
Aurovertin Q9  
Auxin [indole acetate] I2

- B**  
 B gene product [blood groups] R2  
 B specificity [blood groups] S2  
 B, Ba, Bb [complement factors] 3.4.21.46 QR1, QR2  
 B-lymphocyte P2, R3  
 Bacitracin N3  
 Bacterio-chlorophylls [a, b, c] J6, R9, RS10  
 Bacterio-pheophytins R9, RS10  
 Band 3 glycoprotein R2, R3  
 Band 4.1 glycolipid R3  
 Barbiturase 3.5.2.1 J7  
 Bathorhodopsin V4  
 Betaine B8  
 Betaine aldehyde B8  
 Betaine-aldehyde dehydrogenase 1.2.1.8 B8  
 Betaine-homocysteine methyltransferase 2.1.1.5 H3  
 Bile acids L10  
 Bile pigments L5  
 Bilirubin L5  
 Bilirubin diglucuronide L5  
 Bilirubin oxidase 1.3.3.5 L5  
 Biliverdin L5  
 Biliverdin reductase 1.3.1.24 L5  
 Biotin carboxylase 6.3.4.14 J4  
 Bisphosphoglycerate phosphatase 3.1.3.13 D5, U10  
 1,3-Bisphosphoglycerate [1,3-diphosphoglycerate, 3-phospho-D-glyceroyl phosphate] D5, U10  
 2,3-Bisphosphoglycerate [2, 3-diphosphoglycerate, glycerate 2, 3-bisphosphate] D5  
 Bisphosphoglyceromutase 5.4.2.4 D5  
 Bleomycin M7  
 Blood coagulation system S...V1, S...V2  
 Blood group determining structures RS2  
 Bonkrete Q9  
 Borrelidin N4  
 Bradykinin T1, T6  
 Branched-chain amino acids AB9, AB10  
 Branched-chain-amino-acid transaminase 2.6.1.42 B9, B10  
 Brefeldin A S4  
 Bromoconduritol S5  
 Bufotinine I2  
 Bundle-sheath cell V9  
 $\alpha$ -Bungartotoxin V4  
 (*R, R*)-2, 3-Butanediol A10  
 (*R, R*)-Butanediol dehydrogenase 1.1.1.4 A10  
 1-Butanol L3  
 Butanol dehydrogenase L3  
 Butyraldehyde L3  
 Butyraldehyde dehydrogenase L3  
 Butyrate L3  
 Butyrate kinase 2.7.2.7 L3  
 Butyryl-CoA L3  
 Butyryl-CoA dehydrogenase 1.3.99.25 L3  
 Butyryl-enzyme E7  
 Butyryl-malonyl-enzyme E7  
 Butyrylphosphate L3
- C**  
 c-Fos Q7, U4  
 c-Jun Q7  
 c-Myb P7  
 c-Myc Q7, U4  
 c-Raf Q7  
 C1qr<sub>2</sub>S<sub>2</sub> [complement factor] 3.4.21.41...42 Q1, Q2  
 C2, C2a, C2b [complement factors] QR1  
 C3, C3a, C3b, C3c, C3d, C3f, C3g, C3 (H<sub>2</sub>O) [complement factors] QR1, QR2  
 C4, C4a, C4b, C4c [complement factors] QR1, QR2  
 C4bp, C8bp [complement factor binding proteins] QRS1, QRS2  
 C5, C5a, C5b [complement factors] RS1, RS2  
 C6, C7, C8, C9 [complement factors] RS1, RS2  
 CAAT-box Q7  
 Cadaverine K3  
 Calcium channel S4, S5, V3  
 Calcium channel, L-type U3  
 Calcium effects T5  
 Calcium transporting ATPase 3.6.1.38 S5  
 Calmodulin T5, U3, TU5, U6  
 Calsequestrin S5  
 Calvin cycle U9, U10  
 Cap protein M6  
 Capping [of mRNA] PQ6  
 Carbamate kinase 2.7.2.2 G8  
 Carbamoyl-L-asparate G8  
 Carbamoyl-phosphate G8  
 Carbamoyl-phosphate synthase (ammonia) 6.3.4.16 G8  
 Carbamoyl-phosphate synthase (glutamine-hydrolyzing) 6.3.5.5 G8  
 N-Carbamoylsarcosine F7  
 N-Carbamoylsarcosine amidase 3.5.1.59 F7  
 N-Carbamyl-L-glutamate G2  
 Carbon-monoxide dehydrogenase 1.2.99.2 A7, A8, N9  
 3-Carboxy-3-hydroxyisocaproate A9  
 $\gamma$ -Carboxyglutamate I7  
 1-(Carboxyphenylamino)-1-deoxyribose-5'-phosphate G3  
 O<sup>5</sup>-(1-Carboxyvinyl)-3-phosphoshikimate E3  
 Cardiolipin D7  
 Carnitine F6  
 Carnitine acetyltransferase 2.3.1.7 F6  
 Carnitine palmitoyltransferase 2.3.1.21 E8  
 Carnosine G4  
 Carnosine synthase 6.3.2.11 G4  
 $\alpha$ -Carotene E9  
 $\beta$ -Carotene E9  
 $\beta$ -Carotene 15, 15'-dioxygenase 1.13.11.21 E9  
 Carotenoids DE9  
 Casein kinase II P7  
 Castanospermine S5  
 Catalase 1.11.1.6 K5  
 Catechol E3  
 Catechol 1, 2-dioxygenase 1.13.11.1 E3  
 Catechol 2, 3-dioxygenase 1.13.11.2 E3  
 Catechol methyltransferase 2.1.1.6 H2  
 CD 2 P2, P3  
 CD 3 Q3  
 CD-3 accessory glycoproteins Q3  
 CD 4 Q2, Q3  
 CD 8 OP2, Q3  
 CD 9 [platelet surface receptor] UV1  
 CD 11a/18 [LFA-1] P2, P3  
 CD 54 [ICAM-1] P2, P3  
 CD 58 [LFA-3] P2, P3, Q2  
 CDP-1, 2-diacylglycerol A3, C7, T3  
 CDP-choline C8  
 CDP-diacylglycerol-glycerol-3-phosphate 3-phosphatidyltransferase 2.7.8.5 C7  
 CDP-diacylglycerol-inositol 3-phosphatidyltransferase 2.7.8.11 C7, U3, U4  
 CDP-diacylglycerol-serine O-phosphatidyltransferase 2.7.8.8 C7  
 CDP-ethanolamine C7  
 Cell envelope MN2, MN3  
 Cellobiose A4  
 Cellobiose phosphorylase 2.4.1.20 A4  
 Cellular immune interactions O...Q2  
 Cellulase 3.2.1.4 A4  
 Cellulose A4  
 Cellulose synthase (GDP-forming) 2.4.1.29 A5  
 Cellulose synthase (UDP-forming) 2.4.1.12 A5  
 Cephalosporin C K3, K4, O3  
 Ceramide C8  
 Ceramide cholinephosphotransferase 2.7.8.3 C8  
 Ceramide galactosyltransferase Q4  
 Ceramide glucosyltransferase 2.4.1.80 Q4  
 Chemolithotrophy N9, N10  
 Chemotaxis receptor V3  
 Chendeoxycholate J10  
 Chitin D4  
 Chitobiose D3  
 Chitobiosyl-diphosphodolichol a-mannosyltransferase 2.4.1.142 R5  
 Chlatrin S3  
 Chloramphenicol M3  
 Chlorophyll [a, b] E10, K6  
 Chlorophyllase 3.1.1.14 K6  
 Chlorophyllide a E10, K6  
 Chloroplasts R...T9  
 Cholate K10  
 Cholate-CoA ligase 6.2.1.7 K10  
 Cholecalciferol [vitamin D3] F10  
 Cholera toxin U3, U4  
 Cholest-5-ene-3 $\beta$ , 7 $\alpha$ -diol 3 $\beta$ -dehydrogenase 1.1.1.181 H10  
 $\Delta^5$ , 24-Cholestadien-3 $\beta$ -ol G10  
 $\Delta^7$ , 24-Cholestadien-3 $\beta$ -ol G10  
 $\Delta^8$ , 24-Cholestadien-3 $\beta$ -ol F10  
 Cholestanetriol 26-monooxygenase 1.14.13.15 J10  
 $\Delta^4$ -Cholesten-3-on H10  
 $\Delta^7$ -Cholesten-3 $\beta$ -ol G10  
 Cholesterol G10, S2, S4  
 Cholesterol acyltransferase 2.3.1.26 G10, T4  
 Cholesterol ester G10, ST3, ST4  
 Cholesterol esterase 3.1.1.13 G10, S4, U4  
 Cholesterol monooxygenase (side-chain cleaving) 1.14.15.6 H10  
 Choline B8, V4  
 Choline acetyltransferase 2.3.1.6 B8  
 Choline dehydrogenase 1.1.99.1 B8  
 Choline kinase 2.7.1.32 B8  
 Choline oxidase 1.1.3.17 B8  
 Cholinephosphotransferase 2.7.8.2 C8  
 Choloyl-CoA K10  
 Choloylglycine hydrolase 3.5.1.24 KL10



Squares A...L refer to part 1, squares M...V to part 2.

Chondroitin sulfotransferase 2.8.2.5 K4  
 Chondroitinsulfate Q3  
 Chorismate E3  
 Chorismate mutase 5.4.99.5 E3  
 Chorismate synthase 4.6.1.4 E3  
 Christmas factor [factor IX / IXa] 3.4.21.22 UV1  
 Chromatin R8  
 Chylomicra S3  
 Chylomicra remnants S3  
 (S)-Citramalate I6  
 Citrate F6  
 Citrate (*pro*-3-S)-lyase 4.1.3.6 F6  
 Citrate (*si*)-synthase 4.1.3.7 F5  
 Citrate cycle FG5, FG6  
 Citrulline G8  
 Classical complement pathway C3/C5 convertase 2.4.21.43 R1, R2  
 CMP-N-acetylneuraminase F3  
 CMP-sialate F3  
 CO<sub>2</sub> pumping (C<sub>4</sub> plants) V9, V10  
 Coagulation control V1, V2  
 Coagulation factors II, IIa, V, Va, VII, VIIa, VIII, VIIIa, IX, IXa, X, Xa, XI, XIa, XII, XIIa, XIII, XIIIa 3.4.21.x T...V1, T...V2  
 Coagulation [of blood] S...V1, S...V2  
 Coated pit S3  
 Coating proteins [of membranes] S4  
 Cobalamin [vitamin B<sub>12</sub>] I6  
 Cobyrinate diamide H6  
 Coenzyme A [CoA] D10+others  
 Coenzyme B<sub>12</sub> B8, J6  
 Coenzyme F<sub>420</sub> B8  
 Coenzyme F<sub>430</sub> I6  
 Collagen UV1  
 Collagen receptor [platelet surface, GP Ia/IIa] U1, U2  
 Complement factor 1 inhibitor [C1-INH] T1  
 Complement factor 4b binding protein [C4BP] QR2, V1  
 Complement receptor I [CD 35] P3, Q2  
 Complement system Q...S1, Q...S2, U2  
 Coproporphyrin I J5  
 Coproporphyrin III J5  
 Coproporphyrinogen I I5, J5  
 Coproporphyrinogen III J5  
 Coproporphyrinogen oxidase (decarboxylating) 1.3.3.3 J5  
 Coprostanol G10  
 Corrinoids H...J6  
 Cortexone H9  
 Corticoids H10  
 Corticosteroid binding globulin I9  
 Corticosteroids T6  
 Corticosterone G9  
 Corticosterone 18-monooxygenase 1.14.15.5 G9  
 Cortisol I9  
 Cortisone J9  
 Cortisone β-reductase 1.3.1.3 J9  
 Cortol K9  
 Cortolone K9  
 Coumarins UV1, V2  
 Coumeomycin O8  
 CR1 [complement receptor type 1] QR2  
 Creatinase 3.5.3.3 G7  
 Creatine G7, U5  
 Creatine kinase 2.7.3.2 G7, U5  
 Creatine phosphate G7  
 Creatininase 3.5.2.10 G7  
 Creatinine G7  
 Creatinine deiminase 3.5.4.21 G7  
 CREB [A-3, 5-MP responsive element binding protein] P7  
 Crotonyl enzyme E7  
 Crotonyl-CoA J3, L3  
 CTF [CAAT binding protein] P7  
 CTP synthase 6.3.4.2 J7  
 Cyanobacteria R...T9  
 Cyclic AMP [cAMP], see adenosine-3', 5'-monophosphate (cyclic) A6, M6, U3  
 Cyclic electron flow S9, S10  
 3', 5'-Cyclic-GMP phosphodiesterase 3.1.4.35 U4, UV5  
 3', 5'-Cyclic-nucleotide phosphodiesterase 3.1.4.17 A6, U3  
 Cycloartenol synthase 5.4.99.8 F10  
 Cycloheximide P4  
 Cyclomaltodextrin glucanotransferase 2.4.1.19 A5  
 Cycloserine N3  
 5β-Cyprinol sulfate J10  
 L-Cystathionine H4  
 Cystathionine β-lyase 4.4.1.8 G4  
 Cystathionine γ-lyase 4.4.1.1 G4  
 Cystathionine β-synthase 4.2.1.22 H4  
 L-Cysteate I4  
 L-Cysteine C10, H4, H7, K2  
 Cysteine dioxygenase 1.13.11.20 H4  
 Cysteine lyase 4.4.1.10 H4  
 Cysteine reductase (NADH) 1.6.4.1 H4  
 Cysteine transaminase 2.6.1.3 H4  
 Cytidine J7  
 Cytidine 5'-diphosphate [CDP] J7  
 Cytidine 5'-phosphate [CMP] A3, J7  
 Cytidine 5'-triphosphate [CTP] J7  
 Cytidine deaminase 3.5.4.5 J7  
 Cytidylate kinase 2.7.4.14 J7, K7  
 Cytochrome c oxidase [complex IV of mitochondria] 1.9.3.1 P9  
 Cytochrome d complex [*Escherichia coli*] P10  
 Cytochrome f R10, S9  
 Cytochrome o complex [*Escherichia coli*] P10  
 Cytochrome oxidase 1.9.3.1 N10  
 Cytochrome-heme lyase K5  
 Cytochromes a, a<sub>3</sub> K5, P9, QR10  
 Cytochromes b M9, N10  
 Cytochromes b<sub>558</sub>, b<sub>595</sub>, d P10, Q10  
 Cytochromes b<sub>562</sub>, b<sub>555=0</sub> P10, Q10  
 Cytochromes b<sub>L</sub>, b<sub>H</sub> [b<sub>566</sub>, b<sub>562</sub>, in mitochondria] P9, QR10  
 Cytochromes b<sub>L</sub>, b<sub>H</sub> [in chloroplasts] R10, S9, S10  
 Cytochromes c, c<sub>1</sub>, c<sub>2</sub> KL5, M9, N10, P9, QR10, S10  
 Cytoplasm [of bacteria] M3...08  
 Cytoplasmic protein [eucaryotic] O4  
 Cytosine H3, J7  
 Cytosine deaminase 3.5.4.1 J7  
**D**  
 D [complement factor] 3.4.21.46 Q1  
 Daunomycin M8  
 dCTP pyrophosphatase 3.6.1.12 L7  
 Deacetylcephalosporin C K3  
 Deamido-NAD J1  
 Degradation of foreign DNA M2  
 2-Dehydro-3-deoxy-D-glucarate A2  
 2-Dehydro-3-deoxy-D-glucarate aldolase 4.1.2.20 A2  
 2-Dehydro-3-deoxygluconate B3  
 2-Dehydro-3-deoxygluconokinase 2.7.1.45 B4  
 5-Dehydro-4-deoxy-D-glucarate A2  
 2-Dehydro-D-3-deoxy-6-phosphogluconate C4  
 3-Dehydro-L-gulonate B2  
 Dehydro-L-gulonate decarboxylase 4.1.1.34 B2  
 3-Dehydro-L-gulonate dehydrogenase 1.1.1.130 B2  
 2-Dehydro-L-gulonolactone B2  
 Dehydroacyl-CoA D7, E7  
*trans*-2, 3-Dehydroacyl-CoA E8  
*trans*-2, 3-Dehydroacyl-enzyme E7  
 L-Dehydroascorbate C7, G2, H7  
 7-Dehydrocholesterol G10  
 7-Dehydrocholesterol reductase 1.3.1.21 G10  
 11-Dehydrocorticosterone G9  
*cis*-3, 4-Dehydrodecanoyl-ACP E7  
 Dehydrodicolhol pyrophosphate E10  
 Dehydroepiandrosterone I9  
 Dehydroepiandrosterone sulfate I10  
 Dehydrogenases [NAD(P)<sup>+</sup>, general] J1  
 2-Dehydropantoate A10  
 2-Dehydropantoate reductase 1.1.1.169 A10  
 3-Dehydroquininate D3  
 3-Dehydroquininate dehydratase 4.2.1.10 D3  
 3-Dehydroquininate synthase 4.6.1.3 D3  
 3-Dehydroshikimate D3  
 3-Dehydroshinganine B8  
 3-Dehydroshinganine reductase 1.1.1.102 B8  
 5α-Dehydrotestosterone J9  
 2'-Deoxy-5-hydroxymethylcytidine 5'-diphosphate L7  
 2'-Deoxy-5-hydroxymethylcytidine 5'-phosphate L7  
 2'-Deoxy-5-hydroxymethylcytidine 5'-triphosphate L7  
 2'-Deoxyadenosine I1, L7  
 2'-Deoxyadenosine 5'-diphosphate [dADP] I2  
 2'-Deoxyadenosine 5'-phosphate [dAMP] I2  
 2'-Deoxyadenosine 5'-triphosphate [dATP] I2  
 5'-Deoxyadenosine cobalamin [coenzyme B<sub>12</sub>] J6  
 Deoxyadenylate kinase 2.7.4.11 I2  
 Deoxycholate L10  
 11-Deoxycorticosterone H9  
 11-Deoxycortisol I9  
 21-Deoxycortisol I9  
 2'-Deoxycytidine K7  
 2'-Deoxycytidine 5'-diphosphate [dCDP] L7  
 2'-Deoxycytidine 5'-phosphate [dCMP] K7  
 2'-Deoxycytidine 5'-triphosphate [dCTP] L7  
 Deoxycytidine kinase 2.7.1.74 K7  
 Deoxycytidylate deaminase K7  
 Deoxycytidylate hydroxymethyltransferase 2.1.2.8 K7  
 2'-Deoxyguanosine I1, L7  
 2'-Deoxyguanosine 5'-diphosphate [dGDP] I1

2'-Deoxyguanosine 5'-phosphate [dGMP] I1	Dihydrodipicolinate synthase 4.2.1.52 G3	2, 5-Dihydroxypyridine K1	Dolichyl-phosphate $\beta$ -glucosyltransferase 2.4.1.117 R5
2'-Deoxyguanosine 5'-triphosphate [dGTP] I1	7, 8-Dihydrofolate A7, L2, K7	Diiodo-L-tyrosine G2	Dolichyl-phosphate-glucose-glycolipid $\alpha$ -glucosyltransferase R5
Deoxyribodipyrimidine photo-lyase [photoreactivating enzyme] 4.1.99.3 MN7	Dihydrofolate reductase 1.5.1.3 L2	Dimethylallylpyrophosphate D10	Dolichyl-phosphate-mannose-glycolipid $\alpha$ -mannosyltransferase 2.4.1.130 R5
Deoxyribonuclease (apurinic or apyrimidinic) 3.1.25.2 N8	Dihydrofolate synthase 6.3.2.12 L2	Dimethylallyltransferase 2.5.1.1 D10	Dolichyl-phosphate mannosyltransferase 2.4.1.83 R5
Deoxyribonuclease (pyrimidine dimer) 3.1.25.1 N7	Dihydrolipoamide acetyltransferase 2.3.1.12 F5	Dimethylcitrate A9	Dopa decarboxylase [see aromatic L-amino-acid decarboxylase] 4.1.1.28 G2
Deoxyribonuclease I 3.1.21.1 L7	Dihydrolipoamide dehydrogenase 1.8.1.4 F6, G5	Dimethylglycine B8, I3	Dopamine G2
Deoxyribonuclease II 3.2.22.1 L7	Dihydrolipoamide succinyltransferase 2.3.1.61 G5	Dimethylglycine dehydrogenase 1.5.99.2 B8	Dopamine $\beta$ -monooxygenase 1.14.17.1 G2
Deoxyribonucleic acid MN7, QR7+others	7, 8-Dihydromethanopterin K2	2, 3-Dioxo-L-gulonate C2	Dopaquinone G2
2'-Deoxyribose 1-phosphate K8	Dihydroneopterin aldolase 4.1.2.25 L1	Diphosphomevalonate decarboxylase 4.1.1.33 D10	dTMP kinase 2.7.4.9 K7
Deoxythymidine-diphosphate-D-galactose B5	Dihydroorotate 3.5.2.3 H8	Diphtheria toxin O3	dUTP pyrophosphatase 3.6.1.23 K8
Deoxythymidine-diphosphate-D-glucose B5	Dihydroorotate dehydrogenase 1.3.99.1 H8	Diterpenes E10	
Deoxythymidine-diphosphate-L-rhamnose B5	Dihydropteridine reductase 1.6.99.7 K1	DNA (adenosine-N <sup>6</sup> -)-methyltransferase N7	
2'-Deoxyuridine 5'-diphosphate [dUDP] L8	7, 8-Dihydropteroate L2	DNA (cytosine-5-)-methyltransferase 2.1.1.37 H3	
2'-Deoxyuridine 5'-phosphate [dUMP] K8	Dihydropteroate synthase 2.5.1.15 L2	DNA degradation J1, L7	
2'-Deoxyuridine 5'-triphosphate [dUTP] L8	Dihydropyrimidinase 3.5.2.2 J8, L8	DNA double helix M8, QR8	
Dephospho-CoA C10	Dihydrothymine L8	DNA excision-repair MN7, MN8, PQ8	
Dephospho-CoA kinase 2.7.1.24 C10	Dihydrouracil J8	DNA helicase MNO8, N7	
14-Desmethyl-lanosterol F10	Dihydrouracil dehydrogenase (NAD <sup>+</sup> ) 1.3.1.1 J8	DNA polymerase [virus integration] Q8	
Desmosterol G10	Dihydrouracil dehydrogenase (NADP <sup>+</sup> ) 1.3.1.2 J8, L8	DNA replication [in eubacteria] K1, L1, M...O7, M...O8	
Desmosterol reductase G10	1, 4-Dihydroxy-2-naphtoate D3	DNA replication [in eukaryotes] K1, L1, Q...S7, Q...S8	
Dextran A4	11 $\beta$ , 21-Dihydroxy-3, 20-oxo-5 $\beta$ -pregnan-18-al F9	DNA superhelix M8	
Dextranucrase 2.4.1.5 A4	2, 3-Dihydroxy-3-methylvalerate A9	DNA topoisomerase (ATP hydrolyzing) [DNA topoisomerase type II, DNA gyrase] 5.99.1.3 N7, N8, S7, S8	
$\alpha$ -Dextrin endo-1, 6 $\alpha$ -glucosidase 3.2.1.41 A6	3 $\alpha$ , 12 $\alpha$ -Dihydroxy-5 $\beta$ -chol-6-enoate L10	DNA topoisomerase [type I] 5.99.1.2 RS6, S7	
D-1, 2-Diacylglycerol A3, D8, S3, T3, V7	7 $\alpha$ , 12 $\alpha$ -Dihydroxy-5 $\beta$ -cholestan-3-one I10	DNA-directed DNA polymerase [I, III: bacterial; $\alpha$ , $\beta$ , $\delta$ , $\epsilon$ : eukaryotic] 2.7.7.7 IJ1, IJ2, L7, O78, Q7, R8, S8, S9	
Diacylglycerol 3-phosphate D7	3 $\alpha$ , 7 $\alpha$ -Dihydroxy-5 $\beta$ -cholestane I10	DNA-directed RNA polymerase [procaryotic; I, II, III: eukaryotic] 2.7.7.6 JK7, JK8, H1, MN6	
Diacylglycerol acyltransferase 2.3.1.20 D7	3 $\alpha$ , 21-Dihydroxy-5 $\beta$ -pregnane-11, 20-dione G9	DNA-uracil glycosylase N8	
Diacylglycerol kinase 2.7.1.107 D8	17 $\alpha$ , 21-Dihydroxy-5 $\beta$ -pregnane-3, 11, 20-trione JK9	DNA-virus PQ8, PQ9	
LL-2, 6-Diaminopimelate J3	11 $\beta$ , 21-Dihydroxy-5 $\beta$ -pregnane-3, 20-dione G9	DnaA, DnaC proteins M8, N8	
meso-2, 6-Diaminopimelate J3	Dihydroxy-acid dehydratase 4.2.1.9 A9, A10	Dolichol-phosphate-mannose-glycolipid $\alpha$ -mannosyltransferase 2.4.1.130 R5	
Diaminopimelate decarboxylase 4.1.1.20 J3	Dihydroxyacetone-phosphate [see glycerone-phosphate] D6	Dolichol E9, Q5	
Diaminopimelate epimerase 5.1.1.7 J3	3 $\beta$ , 17 $\beta$ -Dihydroxyandrost-5-ene I10	Dolichol kinase 2.7.1.108 E9, QR5	
Dietary lipids S2	1, 25-Dihydroxycalciferol F9	Dolichol phosphatase 3.1.3.51 E9	
L-4, 5-Dihydro-orate H8	7 $\alpha$ , 12 $\alpha$ -Dihydroxycholest-4-en-3-one I10	Dolichol phosphate E9, R5	
Dihydrobiopterin [quininoid] F3, G2, H2, K1	17 $\alpha$ , 20 $\alpha$ -Dihydroxycholesterol I10	Dolichol pyrophosphate E9	
2, 3-Dihydrodipicolinate G3	20 $\alpha$ , 22 $\beta$ -Dihydroxycholesterol H10	Dolichyl-diphosphooligosaccharide-protein glycosyltransferase 2.4.1.119 R5	
Dihydrodipicolinate reductase 1.3.1.26 H3	2, 3-Dihydroxyisovalerate A10		
	L-Dihydroxyphenylalanine G2		

**E**

EF1 $\alpha$ , eEF1 $\beta$ , eEF1 $\gamma$  [eukaryotic elongation factors] P3, PQ4  
 EF-G [bacterial elongation factor] M4  
 EF-Tu, EF-Ts [bacterial elongation factors] N3  
 eIF1, eIF2, eIF3, eIF4a, eIF4b, eIF4c, eIF5, eIF6 [or I1, I2, I3, I4a, I4b, I4c, I5, I6] [eukaryot.init.factors] O...Q5  
 Endoplasmic reticulum Q...S4, Q...S5  
 Endosome S3  
 Endothelial cells S1, ST2  
 Enolase 4.2.1.11 D5  
 Enoyl-CoA hydratase 4.2.1.17 C9, C10, E8, K4  
 Enoyl-[acyl-carrier-protein] reductase (NADPH) 1.3.1.10 E7  
 Eosinophilic chemotactic factor of anaphylaxis [ECF- $\alpha$ ] P1  
 Epidermal growth factor receptor [EGF-receptor] T3, U4, V6  
 Epidermal growth factor [EGF] V6  
 L-Epinephrine [adrenaline] H2, V3  
 eRF [eukaryotic release factor] OP4  
 ERK V7  
 Ergocalciferol [vitamin D<sub>2</sub>] F9  
 Ergosta-5, 7, 22, 24(28)-tetraen-3 $\beta$ -ol F10  
 Ergosterol F9  
 Erythrocyte membrane R3  
 D-erythro-neopterin L1  
 Erythromycin M4  
 D-Erythrose 4-phosphate C5, U9  
*Escherichia coli* OP10  
 Estradiol 17 $\beta$ -dehydrogenase 1.1.1.62 K9, K10



Squares A...L refer to part 1, squares M...V to part 2.

Estradiol-17 $\beta$  K9  
 Estriol K10  
 Estriol 2-hydroxylase K9  
 Estrogen receptor U6  
 Estrogens K10  
 Estrone K9  
 Estrone sulfotransferase 2.8.2.4 K4, K9  
 Ethanol E6  
 Ethanolamine B7, D7, O3  
 Ethanolamine kinase 2.7.1.82 B7  
 Ethanolamine phosphotransferase 2.7.8.1 C7  
 Ethanolamine-phosphate cytidylyltransferase 2.7.7.14 C7  
 Etiocholan-3 $\alpha$ -ol-17-one L10  
 Eubacteria M2...O8  
 Eukaryotes O1...V7  
 Excitons RS9, RS10, ST9  
 Exonuclease [viral] P8  
 Exoribonuclease II 3.1.13.1 O6  
 Extrinsic pathway inhibitor [EPI, LACI] V1  
 Extrinsic pathway of blood coagulation [cf.note 79] UV1

**F**  
 F(ab')<sub>2</sub>-fragment [of immunoglobulins] Q2  
 Fab-fragment [of immunoglobulins] Q2  
 Factor III [methanogenesis] A8  
 Factor P865 [purple bacteria] R10, S10  
 Factors A<sub>0</sub>, A<sub>1</sub>, A, B, P680, P700, X, Z [chloroplasts] R9, S9  
 $\sigma^{54}$ -,  $\sigma^{70}$ -Factors [bacterial transcription] MN6  
 Farnesyltransferase 2.5.1.29 E10  
 Farnesyl-diphosphate farnesyltransferase 2.5.1.21 E10  
 Farnesylpyrophosphate E10  
 Fatty acid D8, S3  
 Fatty acid oxidation E8, J3  
 Fatty acid synthesis E7  
 Fc $\epsilon$ -receptor O3, P1  
 Fc $\gamma$ -receptor II [CD 32] P3, Q2  
 Fc-fragment [of immunoglobulins] Q3  
 Ferredoxin G5, G8, H10, MN10, N9, R9, ST9  
 Ferric reductase M10  
 Ferrochelatase 4.99.1.1 J5  
 Fibrin degradation products [FDP D, E, X, Y] V2  
 Fibrin, fibrin I (soluble), I<sub>n</sub>, II<sub>n</sub>, fibrin (insoluble) UV2

Fibrinogen UV2  
 Fibrinogen receptor [platelet surface, GP IIb/IIIa] UV2  
 Fibrinolysis UV2  
 Fibronectin receptor [platelet surface, GP Ic/IIa] U1, U2  
 Ficoprenol pyrophosphate E9  
 Fletcher factor [plasma prekallikrein] S1, T1, T2  
 Fluorophosphates, organic V4  
 fMet peptides V3  
 Folate KL2  
 Follicle-stimulating-hormone [FSH] receptor V3  
 Folylpolyglutamates HI3  
 Formaldehyde dehydrogenase 1.2.1.46 D5  
 Formamidase 3.5.1.49 J2  
 Formate A7, D5, G5, J2, M4, M9, N10, Q9, Q10  
 Formate acetyltransferase 2.3.1.54 F5  
 Formate dehydrogenase 1.2.1.2 D5, G5  
 Formate dehydrogenase (cytochrome) 1.2.2.1 G5, M9, Q10  
 Formate-tetrahydrofolate ligase 6.3.4.3 A7  
 5-Formimino-tetrahydrofolate A7, G2  
 Formiminoglycine A7, H1  
 Formiminotetrahydrofolate cyclodeaminase 4.3.1.4 A7  
 N-Formimino-L-glutamate A8, F2  
 Formyl polypeptide M4  
 N-Formyl-1-glutamate A7  
 Formyl-CoA G5  
 Formyl-CoA hydrolase 3.1.2.10 G5  
 N-Formyl-L-methionyl-tRNA I3  
 5-Formyl-tetrahydrofolate A7, B8  
 10-Formyl-tetrahydrofolate A7, D2, F2, N4  
 5-Formyl-tetrahydrofolate cyclo-ligase 6.3.3.2 B7  
 N-Formylkynurenine J2  
 Formylmethanofuran A8  
 Formylmethanofuran-tetrahydro-methanopterin formyltransferase 2.3.1.101 A8  
 Formyltetrahydrofolate deformylase 3.5.1.10 A7  
 5-Formyltetrahydromethanopterin A8  
 $\beta$ -Fructofuranosidase [invertase] 3.2.1.26 A4  
 Fructokinase 2.7.1.4 C6  
 $\beta$ -D-Fructose A4, C6

$\beta$ -D-Fructose 1, 6-bisphosphate C5, U9, V9  
 $\beta$ -D-Fructose 1-phosphate C6  
 D-Fructose 2, 6-bisphosphate C6  
 $\beta$ -D-Fructose 6-phosphate A4, C5, U9  
 Fructose bisphosphatase 3.1.3.11 C5, D5, U9  
 Fructose-2, 6-bisphosphatase 3.1.3.46 C6  
 Fructose-bisphosphate aldolase 4.1.2.13 C5, C6, U9  
 Fucosyltransferase R4  
 Fumarate F8, G5, H3, K1, M9, MN10, O9, O10, Q10, R10, S10  
 Fumarate hydratase [fumarase] 4.2.1.2 F5  
 Fumarate reductase M10, Q10  
 Fumarylacetoacetase 3.7.1.2 H3  
 4-Fumarylacetoacetate G3  
 Fusidinic acid M4, P4

**G**  
 G-Protein UV3, UV4  
 G-Substrate [in cerebellum] U5  
 Galactokinase 2.7.1.6 B4  
 D-Galactose B4  
 $\alpha$ -D-Galactose 1-phosphate B4  
 Galactose-1-phosphate thymidyltransferase 2.7.7.32 B5  
 $\alpha$ -Galactosidase 3.2.1.22 B4  
 $\beta$ -Galactosidase 3.2.1.23 B4  
 $\alpha$ -Galactoside B4  
 $\beta$ -Galactoside  $\alpha$ -2, 6-sialyltransferase 2.4.99.1 RS3, R4  
 Galactosyl ceramide Q4  
 $\beta$ -1, 3-Galactosyl-O-glycosyl-glycoprotein  $\beta$ -1, 3-N-acetylglucosaminyltransferase 2.4.1.146 R4  
 $\beta$ -1, 3-Galactosyl-O-glycosyl-glycoprotein  $\beta$ -1, 6-N-acetylglucosaminyltransferase 2.4.1.102 R4  
 D-Galacturonate B3  
 D-Galacturonate 1-phosphate B3  
 Galacturonokinase 2.7.1.44 B3  
 Gangliosides C8, Q3  
 Gauchers disease Q4  
 GC box P7, Q7  
 GDP-D-glucose B5  
 GEF [guanyl nucleotide exchange factor] P5  
 Genetic code P8  
 Gentamicin M4, N4  
 Geranylgeranyldiphosphate geranylgeranyltransferase 2.5.1.32 E10  
 Geranylgeranylpyrophosphate E10  
 Geranyltransferase 2.5.1.10 E10

Germline DNA P7  
 Geranylpyrophosphate D10  
 Gestagens H9, H10  
 Globin K5, L5  
 Glucagon receptor V3  
 Glucan 1, 4- $\alpha$ -glucosidase [glucoamylase] 3.2.1.3 A6  
 1, 4 $\alpha$ -Glucan branching enzyme 2.4.1.18 A5  
 ( $\alpha$ -Glucan) phosphorylase 2.4.1.1 A5  
 Glucan-1, 4 $\alpha$ -glucosidase [glucoamylase] 3.2.1.3 A6  
 D-Glucarate A2  
 D-Glucarate dehydratase 4.2.1.40 A2  
 Glucocorticoid receptor U6  
 Glucokinase 2.7.1.2 B6  
 D-Gluconate B6  
 Gluconeogenesis B5...F5  
 D-Glucono-1, 5-lactone B6  
 D-Glucono-1, 5-lactone 6-phosphate C5  
 Gluconolactonase 3.1.1.17 B7  
 Glucosaminatase D3  
 D-Glucosamine D4  
 D-Glucosamine 6-phosphate D4  
 Glucosamine acetyltransferase 2.3.1.3 D4  
 Glucosamine kinase 2.7.1.8 D4  
 Glucosamine-phosphate acetyltransferase 2.3.1.4 D4  
 Glucosaminophosphate isomerase 5.3.1.10 C4  
 Glucocorticoids I9  
 D-Glucose A4, B4, C6, C8, M6, N2, N3  
 $\alpha$ -D-Glucose 1, 6-bisphosphate B5  
 $\alpha$ -D-Glucose 1-phosphate A4, B5, U6, U9  
 $\alpha$ -D-Glucose 6-phosphate A4, C5, UV9  
 Glucose dehydrogenase 1.1.1.47 B6  
 Glucose oxidase 1.1.3.4 B6  
 Glucose-1-phosphate adenyltransferase 2.7.7.27 B5, B6  
 Glucose-1-phosphate phosphodismutase 2.7.1.41 B6  
 Glucose-1-phosphate thymidyltransferase 2.7.7.24 B5  
 Glucose-6-phosphatase 3.1.3.9 C6  
 Glucose-6-phosphate dehydrogenase 1.1.1.49 C5  
 Glucose-6-phosphate isomerase 5.3.1.9 C5, U9  
 $\alpha$ -Glucosidase 3.2.1.20 A4, A6  
 $\beta$ -Glucosidase 3.2.1.21 A3, A4

β-Glucosides A3	γ-Glutamyl transferase 2.3.2.2 T7	Glycine formiminotransferase 2.1.2.4 A7, H2	Guanidinoacetate kinase 2.7.3.1 G7
Glucosyl ceramide C8, Q4	L-Glutamyl-tRNA H7	Glycine hydroxymethyltransferase 2.1.2.1 B7	Guanidinoacetate methyltransferase 2.1.1.2 G7
Glucosylceramidase 3.2.1.45 C8	Glutamyl-tRNA <sup>Glu</sup> reductase H6	Glycine receptor V4	Guanidinoacetate phosphate G7
Glucosyltransferases 2.4.1.x A3	L-γ-Glutamylcysteine H7	Glycine transaminase 2.6.1.4 B7	4-Guanidinobutanamide F7
D-Glucuronate B3	Glutarate J3	Glycine-N-choloyltransferase 2.3.1.65 K10	L-Guanidinobutanamide deaminase F7
D-Glucuronate 1-phosphate B3	Glutaryl-CoA J3	Glycine-tRNA ligase 6.1.1.14 G5	4-Guanidinobutyrase 3.5.3.7 F7, H6
Glucuronate reductase 1.1.1.19 B2	Glutaryl-CoA dehydrogenase 1.3.99.7 J3	Glycocholate L10	4-Guanidinobutyrate F7
Glucuronate-1-phosphate uridylyltransferase 2.7.7.44 B3	Glutaryl-CoA ligase 6.2.1.6 J3	Glycogen A5, U5, U6	Guanine H1
β-Glucuronidase 3.2.1.31 A3, L6	Glutathione dehydrogenase (ascorbate) 1.8.5.1 B2, HI7	Glycogen phosphorylase 2.4.1.1 A5	Guanine deaminase 3.5.4.3 G1
β-D-Glucuronide A3, D9, F9, F10, J2, K9, K10, L9, L10	Glutathione reductase (NAD(P)H) 1.6.4.2 HI7	Glycogen synthase kinase 3 2.7.1.37 Q7, U5, U6	Guanosine G1, K7
Glucuronokinase 2.7.1.43 B3	Glutathione synthase 6.3.2.3 H7	Glycogen synthase [D, I] 2.4.1.11 A5, U4, T5, U5, U6	Guanosine 5'-diphosphate [GDP] H1
D-Glucuronolactone A2	Glutathione transferase 2.5.1.18 H7	Glycogen synthesis U5, U6	Guanosine 5'-phosphate [GMP] G1, U5
Glucuronolactone reductase 1.1.1.20 A2	Glutathione transhydrogenases 1.8.4.x H7	Glycogen-synthase-D phosphatase [protein phosphatase 1] 3.1.3.42 A6, UV5, UV6	Guanosine 5'-triphosphate [GTP] H1, K1, V5
Glucuronosyl transferase 2.4.1.17 A3	Glutathione, oxidized [GSSG] B2, I7	Glycolaldehyde K1, L1	Guanosine-3', 5'-phosphate [cyclic, G-3, 5-MP, cGMP] V5
Glutaconyl-CoA J3	Glutathione, reduced [GSH] B2, H7	Glycolate E5, F6, T10	Guanylate cyclase 4.6.1.2 V5
D-Glutamate O4	D-Glyceraldehyde D6	Glycolipid anchor of proteins Q5	Guanylate kinase 2.7.4.8 G1, I1
L-Glutamate H7+others	D-Glyceraldehyde 3-phosphate C4, D5, H3, U9	Glycolipid mannosyltransferases 2.4.1.x R5	L-Gulonate B2
Glutamate γ-carboxylase 1.14.99.20 HI7	Glyceraldehyde-3-phosphate dehydrogenase 1.2.1.12 D5	Glycolysis, glycogenolysis B5...F5, U6	L-Gulonate dehydrogenase 1.1.1.45 B2
Glutamate 5-kinase 2.7.2.11 G7	Glyceraldehyde-3-phosphate dehydrogenase (NADP <sup>+</sup> ) 1.2.1.9 D5	Glycophorin R2, R3	L-Gulonolactone B2
Glutamate acetyltransferase 2.3.1.35 G7	Glyceraldehyde-3-phosphate dehydrogenase (phosphorylating) 1.2.1.13 U9	Glycosphingolipids Q4	L-Gulonolactone oxidase 1.1.3.8 B2
Glutamate decarboxylase 4.1.1.15 H6	D-Glycerate D6	Glycyl-tRNA G5	Gyrase O7, O8
Glutamate decarboxylation pathway H5, H6	Glycerate kinase 2.7.1.31 D6	Glyoxylase I [see lactoylglutathione lyase] 4.4.1.5 H5	<b>H</b>
Glutamate dehydrogenase 1.4.1.2...4 G5	Glycero-3-phosphocholine D8	Glyoxylase II [see hydroxyacylglutathione hydrolase] 3.1.2.6 I5	H gene product [blood groups] R2
Glutamate formiminotransferase 2.1.2.5 A7, G3	Glycero-3-phosphoethanolamine D7	Glyoxylate B8, D5, G6, H1, I7, T10	H specificity [O specificity, blood groups] R2
Glutamate group of amino acids H8	L-Glycero-D-mannoheptose O3	Glyoxylate cycle G5, G6	H [complement inactivator] R1, R2
Glutamate racemase 5.1.1.3 O4	Glycerol D6, D8, J2	Glyoxylate dehydrogenase (acylating) 1.2.1.17 G6	H <sup>+</sup> transporting ATP synthase 3.6.1.34 M10, N10, P9, P10, Q10, T9, T10
Glutamate receptor V4	<i>sn</i> -Glycerol 3-phosphate D6, M9, N10	Glyoxylate reductase 1.1.1.26 D5, F6	Hageman factor [factor XII / XIIa] 3.4.21.38 T1
Glutamate synthase (NADPH) 1.4.1.13 G6	Glycerol dehydratase 4.2.1.30 D6	GM2, GM3 gangliosides Q3, Q4	Halobacteria T10
Glutamate-1-semialdehyde 2,1-aminomutase 5.4.3.8 H6	Glycerol dehydrogenase (NADP <sup>+</sup> ) 1.1.1.72 D6	GMP 140 [platelet surface membrane protein] UV1	Haptoglobin KL5
L-Glutamate-5-semialdehyde H6, H7	Glycerol kinase 2.7.1.30 D6	GMP reductase 1.6.6.8 G1	HCO <sub>3</sub> <sup>-</sup> /Cl <sup>-</sup> anion channel R3
Glutamate-5-semialdehyde dehydrogenase 1.2.1.41 H7	Glycerol-3-phosphate acyltransferase 2.3.1.15 D7	GMP synthase 6.3.4.1 G1	Heat shock protein 90 [hsp 90] U6
Glutamate-ammonia ligase 6.3.1.2 G7	Glycerol-3-phosphate dehydrogenase 1.1.99.5 C6, M9	Golgi apparatus Q...S3, Q...S4	Helicase P8, RS8
Glutamate-cysteine ligase 6.3.2.2 H7	Glycerol-3-phosphate dehydrogenase (NAD <sup>+</sup> ) 1.1.1.8 D6	Gram-negative micrororganisms MN2, MN3	Helper cells [CD4 <sup>+</sup> cells] PQ2
Glutamate-tRNA ligase 6.1.1.17 H7	Glycerone phosphate [dihydroxyacetone phosphate] M9, N10, U9	Gram-positive microorganisms NO2, NO3	Heme K5, T6, U6
Glutaminase 3.5.1.2 G7	Glycerophosphocholine phosphodiesterase 3.1.4.2 D7	Granulocyte-macrophage colony-stimulating factor [GM-CSF] O1	Heme oxygenase (decycling) 1.14.99.3 KL5
L-Glutamine H7+others	Glycine B7, D2, F7, G5, G8, H1, H4, H7, K10	Grb 2/SOS1 V7	Hemoglobin K5, T4
Glutamine-fructosamine-6-phosphate transaminase 2.6.1.16 D4	Glycine amidinotransferase 2.1.4.1 F8	GTP cyclohydrolase I 3.5.4.16 K1	Heparin P1, Q3
Glutamine-fructose-6-phosphate transaminase 2.6.1.16 D4	Glycine dehydrogenase (decarboxylating) 1.4.4.2 B7	GTP exchange protein U7	Heparin cofactor II [HC II] V2
L-Glutamyl 5-phosphate G7		GTPase activating protein [GAP] UV7, V6	HER-2 [receptor] V6



Squares A...L refer to part 1, squares M...V to part 2.

Histidine ammonia-lyase 4.3.1.3 F2  
 Histidine decarboxylase 4.1.1.22 F2  
 L-Histidinol E2  
 Histidinol dehydrogenase 1.1.1.23 F2  
 L-Histidinol phosphate E2  
 Histidinol-phosphatase 3.1.3.15 E2  
 Histidinol-phosphate transaminase 2.6.1.9 E2  
 L-Histidinyl-tRNA F2  
 Histones Q8, RS7, R8, U5  
 HIV [human immunodeficiency virus] PQ8  
 Holo-[acyl-carrier-protein] synthase 2.7.8.7 F8  
 Homoaconitate hydratase 4.2.1.36 I3  
 Homo-*cis*-aconitate I3  
 Homocitrate H3  
 Homocitrate synthase 4.1.3.21 H3  
 L-Homocysteine D7, H3  
 Homogentisate G3  
 Homogentisate 1, 2-dioxygenase 1.13.11.5 G3  
 Homoisocitrate I3  
 Homoisocitrate dehydrogenase 1.1.1.155 I3  
 L-Homoserine G4  
 Homoserine dehydrogenase 1.1.1.3 G4  
 Homoserine kinase 2.7.1.39 G4  
 Homoserine succinyltransferase 2.3.1.46 G4  
 5-HPETE T6  
 5-HPETE dehydratase T6  
 HU protein [bacterial DNA replication] M8  
 2-Hydroxyestrone L9  
 3 $\alpha$ -Hdroxysteroid dehydrogenase 1.1.1.50 F9, G9, G10, I10, J9, J10, K9, L9, L10  
 Hydantoin propionate F2  
 Hydrogenase 1.18.99.1 B8, K4, M9, N9, Q10  
 3 $\beta$ -Hydroxy- $\Delta^5$ -steroid dehydrogenase 1.1.1.145 H9, I9, I10, J9, J10, K9  
 3 $\beta$ -Hydroxy-12-oxo-5 $\beta$ -cholanate L10  
 D-4-Hydroxy-2-oxoglutarate I7  
 4-Hydroxy-2-oxoglutarate aldolase 4.1.3.16 I7  
 4-Hydroxy-2-oxovalerate F3  
 4-Hydroxy-2-oxovalerate aldolase G3  
 3-Hydroxy-3-methylglutaryl-CoA D9  
 2-Hydroxy-3-oxopropionate reductase 1.1.1.60 D5  
 7 $\alpha$ -Hydroxy-5 $\beta$ -cholestan-3-one I10  
 3 $\alpha$ -Hydroxy-5 $\beta$ -pregnane-20-one G10  
 21-Hydroxy-5 $\beta$ -pregnane-3, 11, 20-trione G9  
*allo*-4-Hydroxy-D-proline H8  
 (S)-2-Hydroxyacid dehydrogenase 1.1.3.15 G6  
 (S)-2-Hydroxyacid oxidase 1.1.3.15 D5, F6  
 L-3-Hydroxyacyl-CoA E8  
 3-Hydroxyacyl-CoA dehydrogenase 1.1.1.35 C9, E8  
 3-Hydroxyacyl-E/ACP dehydratase 4.2.1.58.61 E7  
 D-3-Hydroxyacyl-enzyme E7  
 Hydroxyacylglutathione hydrolase 3.1.2.6 I5  
 11 $\beta$ -Hydroxyandrost-4-ene-3, 17-dione J9  
 16 $\alpha$ -Hydroxyandrost-4-ene-3, 17-dione J10  
 19-Hydroxyandrost-4-ene-3, 17-dione J9  
 3-Hydroxyanthranilate K2  
 3-Hydroxyanthranilate oxygenase K2  
 4-Hydroxybenzoate E3  
 2-Hydroxybutyrate H4  
 D-3-Hydroxybutyrate E8  
 4-Hydroxybutyrate H5  
 3-Hydroxybutyrate dehydrogenase 1.1.1.30 F8  
 4-Hydroxybutyrate dehydrogenase 1.1.1.61 H6  
 (S)-3-Hydroxybutyryl-CoA L4  
 4-Hydroxybutyryl-CoA H5  
 3-Hydroxybutyryl-CoA dehydratase 4.2.1.55 L3  
 3-Hydroxybutyryl-CoA dehydrogenase 1.1.1.157 L4  
 D-3-Hydroxybutyryl-enzyme E7  
 7 $\alpha$ -Hydroxycholest-4-ene-3-one H10  
 7 $\alpha$ -Hydroxycholesterol H10  
 20 $\alpha$ -Hydroxycholesterol H10  
 17 $\alpha$ -Hydroxycortexone I9  
 18-Hydroxycorticosterone G9  
 16 $\alpha$ -Hydroxydehydroepiandrosterone J10  
 2-Hydroxyestradiol-17 $\beta$  L9  
 16 $\alpha$ -Hydroxyestrone K9  
 2 ( $\alpha$ -Hydroxyethyl)-thiamine pyrophosphate A9, E5  
 L-*erythro*-4-Hydroxyglutamate I7  
 L-4-Hydroxyglutamate semialdehyde I7  
 2-Hydroxyglutarate GH6  
 2-Hydroxyglutarate dehydrogenase 1.1.99.2 G6  
 5-Hydroxyindole acetaldehyde I2  
 5-Hydroxyindole acetate I2  
 (S)-3-Hydroxyisobutyrate C10  
 3-Hydroxyisobutyrate dehydrogenase 1.1.1.31 C10  
 (S)-3-Hydroxyisobutyryl-CoA C10  
 3-Hydroxyisobutyryl-CoA hydrolase 3.1.2.4 C10, K4  
 3-Hydroxyisovaleryl-CoA C9  
 3-Hydroxykynurenine K2  
 Hydroxylamine M10, N10  
 Hydroxylamine dehydrogenase N10  
 Hydroxylysine kinase 2.7.1.81 K3  
 Hydroxymethylglutaryl-CoA lyase 4.1.3.4 DE9  
 Hydroxymethylglutaryl-CoA reductase 1.1.1.88 D9  
 Hydroxymethylglutaryl-CoA reductase (NADPH) 1.1.1.34 D9  
 [Hydroxymethylglutaryl-CoA reductase (NADPH)] kinase 2.7.1.109 D9  
 [Hydroxymethylglutaryl-CoA reductase (NADPH)] phosphatase 3.1.3.47 D9  
 Hydroxymethylglutaryl-CoA synthase 4.1.3.5 DE8  
 2-Hydroxyruconate semialdehyde F3  
 Hydroxyruconate semialdehyde hydrolase F3  
 6-Hydroxynicotinate J1  
 4-Hydroxyphenylpyruvate F3  
 4-Hydroxyphenylpyruvate dioxygenase 1.13.11.27 F3  
 17 $\alpha$ -Hydroxypregnenolone I9  
 21-Hydroxypregnenolone H9  
 11 $\beta$ -Hydroxyprogesterone I9  
 17 $\alpha$ -Hydroxyprogesterone I9  
 L-4-Hydroxyproline H7  
 4-Hydroxyproline epimerase 5.1.1.8 H7  
 2-Hydroxypropionaldehyde D6  
 3-Hydroxypropionate K4  
 3-Hydroxypropionate dehydrogenase 1.1.1.59 K4  
 3-Hydroxypropionyl-CoA K4  
 Hydroxypyruvate B7, D6  
 Hydroxypyruvate reductase 1.1.1.81 D6  
 11 $\beta$ -Hydroxysteroid dehydrogenase 1.1.1.146 F9, G9, J9  
 20 $\beta$ -Hydroxysteroid dehydrogenase F9, F10, K9  
 19-Hydroxytestosterone J9  
 5-Hydroxytryptophan H2  
 Hygromycin M4, N4  
 Hyperpolarization [of membranes] V5  
 Hypotaurine I4  
 Hypotaurine dehydrogenase 1.8.1.3 I4  
 Hypoxanthine G1  
 Hypoxanthine phosphoribosyltransferase 2.4.2.8 G1, G2  
 I  
 I [complement inactivator] 3.4.21.45 R2  
 L-Iditol dehydrogenase 1.1.1.14 C6  
 IF-1, IF-2, IF-3 [initiation factors for translation] MN5  
 Ig- $\beta$  R3  
 IgE receptor V3  
 IgE-antigen complex V3  
 IgM- $\alpha$  R3  
 Imidazole U6  
 Imidazole acetaldehyde F2  
 Imidazoleacetol phosphate E2  
 D-*erythro*-Imidazoleglycerol phosphate E2  
 Imidazoleglycerol-phosphate dehydratase 4.2.1.19 E2  
 4-Imidazolone-5-propionate F2  
 Imidazolonepropionase 3.5.2.7 F2  
 Immediate type hypersensitivity [type I] OP1, OP2  
 Immunoglobulin A [IgA] R2  
 Immunoglobulin D [IgD] R2  
 Immunoglobulin diversity OP6, OP7  
 Immunoglobulin E [IgE] P1, R2  
 Immunoglobulin G [IgG] Q1, Q2, R2  
 Immunoglobulin M [IgM] Q1, QR2, QR3  
 Immunoglobulin superfamily O...R2, O...R3  
 IMP cyclohydrolase 3.5.4.10 F2  
 IMP dehydrogenase 1.1.1.205 F1  
 Indole H3  
 Indole-glycerol-3-phosphate synthase 4.1.1.48 G3  
 Indoleacetaldehyde I2  
 Indoleacetate [auxin] J2  
 Indolelactate I2  
 Indolepyruvate H2  
 (3-Indolyl)glycerol 3-phosphate G3  
 Initiation factor C6 U4  
 Initiator proteins [licensing factors] RS8  
 Initiator region Q7  
 Inner nuclear membrane S6  
 Inorganic pyrophosphatase 3.6.1.1 J4, S8

Inosine G1	Interferon $\gamma$ [IFN- $\gamma$ ] O1, P2	<b>J</b>	Le gene product [blood groups] R2
Inosine 5'-phosphate [IMP] G2	Interferon- $\gamma$ receptor P2	JNK U7	Le <sup>a</sup> specificity [blood groups] R2
<i>myo</i> -Inositol A3, B7, TU4	Interleukin 1 $\alpha$ [IL-1 $\alpha$ ] O1, P2	<b>K</b>	Le <sup>b</sup> specificity [blood groups] R2
1D- <i>myo</i> -Inositol 1, 2, 3, 4, 5, 6-hexakisphosphate [phytate] T4, T5	Interleukin 1 $\beta$ [IL-1 $\beta$ ] O1, P2	Kanamycin M4, N4	L-1-Lecithin C8, U5
1D- <i>myo</i> -Inositol 1, 2, 3, 4, 5-pentakisphosphate T4, T5	Interleukin 2 [IL-2] O1, P2	Kasugamycin M5	L-Leucine B9
1D- <i>myo</i> -Inositol 1, 2, 4, 5, 6-pentakisphosphate T4, T5	Interleukin 3 [IL-2] O1	Keto... [see oxo...]	Leucine dehydrogenase 1.4.1.9 B9
1D- <i>myo</i> -Inositol 1, 3, 4, 5, 6-pentakisphosphate T4	Interleukin 4 [IL-4] O1, P2	Ketohexokinase 2.7.1.3 C6	Leucine zipper Q7
Inositolpolyphosphate 4-phosphatase T3	Interleukin 5 [IL-5] O1	Ketol-acid reductoisomerase 1.1.1.86 A9	Leucine-tRNA ligase 6.1.1.4 B9
1D- <i>myo</i> -Inositol 1, 3, 4, 5-tetrakisphosphate T4	Interleukin 6 [IL-6] O1, P2	Ketone bodies F8	L-Leucyl-tRNA B9
1D- <i>myo</i> -Inositol 1, 3, 4, 6-tetrakisphosphate T4	Interleukin-1 receptor [IL-1 receptor] P2	6-Ketoprostaglandin F2 $\alpha$ T7	Leukotriene A <sub>4</sub> T6
Inositol-1, 3, 4, 5-tetrakisphosphate 3-phosphatase T4	Interleukin-2 receptor [IL-2 receptor] P2, U4	Killer cells [CD8 <sup>+</sup> cells] OP2	Leukotriene B <sub>4</sub> P1, T6
Inositol-1, 3, 4, 6-tetrakisphosphate 5-kinase T4	Interleukin-4 receptor [IL-4 receptor] P2	Kininogen, high molecular weight [HK] S1, T1, T2	Leukotriene C <sub>4</sub> P1, T7
1D- <i>myo</i> -Inositol 1, 3, 4-trisphosphate T4	Interleukin-6 receptor [IL-6 receptor] P2	Kynurenate J2	Leukotriene D <sub>4</sub> P1, T7
1D- <i>myo</i> -Inositol 1, 4, 5-trisphosphate T3, T4, V6	Intermediate density lipoprotein [IDL] S3	Kynureninase 3.7.1.3 K2	Leukotriene-A <sub>4</sub> hydrolase T6
1D- <i>myo</i> -Inositol-trisphosphate 3-kinase 2.7.1.127 T4	Intrinsic pathway of blood coagulation [cf.note 79] UV1	L-Kynurenine J2	Leukotriene-C synthase 2.5.1.37 T6
Inositol-trisphosphate receptor U4	Invertase [see $\beta$ -fructofuranosidase] 3.2.1.26 A4	Kynurenine 3-monooxygenase 1.14.13.9 J2	Levan A4
Inositol-1, 3, 4-trisphosphate 6-kinase T4	Iodide peroxidase 1.11.1.8 G2	Kynurenine oxoglutarate transaminase 2.6.1.7 J2	Levansucrase 2.4.1.10 A4
Inositol-1, 4, 5-trisphosphate 5-phosphatase 3.1.3.56 T3	Ion transfer [through cell membranes] RS3, V3, V4, V5	<b>L</b>	Light harvesting antenna complex R9, R10, S9
1D- <i>myo</i> -Inositol 1, 3-bisphosphate T4	Iron M10, N10	L-type calcium channel U4	Limit dextrin A6
1D- <i>myo</i> -Inositol 1, 4-bisphosphate T3, T4	IRS 1/3 V5	<i>lac</i> Repressor N6	Lincomycin M3
1D- <i>myo</i> -Inositol 3, 4-bisphosphate T4	Isobutyryl-CoA B10	Lactaldehyde reductase 1.1.1.77 E6	Lipase T5
Inositol-1, 4-bisphosphate 1-phosphatase 3.1.3.57 T4	Isocaproic aldehyde H10	$\beta$ -Lactamase 3.5.2.6 L4	Lipid A N2
Inositol 1, 4-bisphosphate 4-phosphatase T3	Isochorismate E3	Lactate M9, N10	Lipid metabolism CD7, CD8
<i>myo</i> -Inositol 1-kinase 2.7.1.64 T4	Isochorismate synthase 5.4.99.6 E3	D-Lactate E6, I5	Lipocortin T6
Inositol 3-kinase T4	<i>threo</i> -D <sub>s</sub> -Isocitrate G6	L-Lactate E6	Lipopolysaccharide N2
1L- <i>myo</i> -Inositol 1-phosphatase 3.1.3.25 A3	Isocitrate dehydrogenase (NAD <sup>+</sup> ) 1.1.1.41 G6	Lactate 2-monooxygenase 1.13.12.4 E6	Lipoprotein N2
<i>myo</i> -Inositol 1-phosphate A3, T3, T4	Isocitrate dehydrogenase (NADP <sup>+</sup> ) 1.1.1.42 G6	D-Lactate dehydrogenase 1.1.1.28 E6	Lipoprotein lipase 3.1.1.34 S3
1D- <i>myo</i> -Inositol 3-phosphate T4	Isocitrate lyase 4.1.3.1 G6	L-Lactate dehydrogenase 1.1.1.27 E6, H4	Lipoxygenase 1.13.11.12 T6
1D- <i>myo</i> -Inositol 4-phosphate T4	L-Isoleucine B9, H4	L-Lactate dehydrogenase (cytochrome) 1.1.2.3 E6, M9	Lithocholate J10
Inositol metabolism A3, TU3, TU4, TU5	Isoleucine-tRNA ligase 6.1.1.5 B9	Lactate racemase 5.1.2.1 E6	Low density lipoprotein [LDL] S2, S3
<i>myo</i> -Inositol oxygenase 1.13.99.1 A3	L-Isoleucyl-tRNA B9	Lactose B4, M2, M3	Lumirhodopsin V4
Insoluble immune complex R1	Isopenicillin L3	Lactose permease [LacY] M3	Luteinizing-hormone [LH] receptor V3
Insulin V5, V6	Isopenicillin synthase L3	Lactosyl ceramide Q4	Lycopene E9
Insulin-like-growth-factor-1 [IGF-1] receptor V5	N <sup>6</sup> -Isopentenyl adenosine O4	Lactosylceramide $\alpha$ -2, 3-sialyltransferase 2.4.99.9 Q4	L-Lysine J3
Insulin receptor U4, U7, V5	$\Delta^3$ -Isopentenylidiphosphate D10, O4	S-Lactoyl glutathione I5	Lysine acetyltransferase 2.3.1.32 J3
Integrase [of retrovirus] PQ8	Isopentenylidiphosphate $\Delta$ -isomerase 5.3.3.2 D10	2-( $\alpha$ -Lactoyl)-thiamine pyrophosphate E5, E6	Lysine decarboxylase 4.1.1.18 K3
Integration host factor M5	Isoprenoids DE10	Lactoyl-CoA K4	Lysine metabolism J3
	3-Isopropylmalate A9	Lactoyl-CoA dehydratase 4.2.1.54 J4	Lysine-tRNA ligase 6.1.1.6 J3
	3-Isopropylmalate dehydratase 4.2.1.33 A9	Lactoyl-CoA dehydrogenase K4	L-1-Lysolecithin D8
	3-Isopropylmalate dehydrogenase 1.1.1.85 B9	Lactoylglutathione lyase 4.4.1.5 H5	L-2-Lysolecithin D8
	2-Isopropylmalate synthase 4.1.3.12 B10	Lanosterol F10	L-1 or 2-Lyso phosphatidylethanolamine D7
	Isovaleryl-CoA B9	Lanosterol synthase 5.4.99.7 F10	Lysophospholipase 3.1.1.5 D7, D8
	Itaconate F6	Lathosterol G10	Lysosomal membrane protein [platelet surface, GP 53] U2
		Lathosterol oxidase 1.3.3.2 G10	Lysosome S3
		LDL (low density lipoprotein) S2, S3	Lysozyme 3.2.1.17 N2
		LDL-receptor S2, S3	L-Lysyl-tRNA J3
			L-Lyxonate C2
			<b>M</b>
			M-protein O2, O3
			$\alpha_2$ -Macroglobulin [ $\alpha_2$ M] T1, T2
			Magnesium-2, 4-divinyl-phaeoporphyrin ( $a_5$ )-monomethylester K6



Squares A...L refer to part 1, squares M...V to part 2.

Magnesium-protoporphyrin IX J6  
Magnesium-protoporphyrin methyltransferase 2.1.1.11 J6  
Magnesium-protoporphyrin monomethyl-ester K6  
Major histocompatibility complex class I [MHC class I, HLA antigen] P2, P3  
Major histocompatibility complex class II [MHC class II, HLA antigen] P3, Q2  
(S) (=L)-Malate F5, V9, V10  
Malate dehydrogenase 1.1.1.37 F6  
Malate dehydrogenase (decarboxylating) 1.1.1.39 F5  
Malate dehydrogenase (NADP<sup>+</sup>) 1.1.1.82 V10  
Malate dehydrogenase (oxaloacetate-decarboxylating)(NADP<sup>+</sup>) 1.1.1.40 V9  
Malate synthase 4.1.3.2 F5  
Maleamate K1  
4-Maleylacetoacetate G3  
Maleylacetoacetate isomerase 5.2.1.2 G3  
Malic enzyme 1.1.1.39 F5  
Malonate E4, F4, G4, K7  
Malonate semialdehyde F4, K4  
Malonate-CoA transferase 2.8.3.3 F7, K4  
Malonate-semialdehyde dehydrogenase 1.2.1.15 F4, K4  
Malonate-semialdehyde dehydrogenase (acylating) 1.2.1.18 F4, K4  
Malonyl-CoA F7, L4  
Malonyl-CoA decarboxylase 4.1.1.9 F7  
Maltase [ $\alpha$ -glucosidase] 3.2.1.20 A6  
Maltose A6, N2, N3  
Maltose binding protein [MalE] N3  
Maltose permease [MalF, MalG, MalK] N3  
Maltose phosphorylase 2.4.1.8 A6  
Manganese cluster RS9, R10  
Mannokinase 2.7.1.7 C6  
D-Mannose C6  
Mannose isomerase 5.3.1.7 C6  
 $\alpha$ -D-Mannose 6-phosphate C6  
Mannose-6-phosphate isomerase 5.3.1.8 C6  
Mannose-6-phosphate receptor S3  
 $\alpha$ -1, 3-Mannosyl-glycoprotein  $\beta$ -1, 2-N-acetylglucosaminyltransferase 2.4.1.101 S4  
Mannosyl-oligosaccharide 1, 2- $\alpha$ -mannosidase 3.2.1.113 S5  
Mannosyl-oligosaccharide 1,3-1,6- $\alpha$ -mannosidase 3.2.1.114 RS4  
Mannosyl-oligosaccharide glucosidase [glucosidase I] 3.2.1.106 S5  
MAP-2 T5  
Mast cell O3, P1  
Mature tRNA Q5, Q6  
Mature B-lymphocyte DNA P6, P7  
MCP [membrane cofactor protein] QR1, QR2  
MEK V7  
Melanin G2  
Melantoin I2  
Membrane attachment [of ribosomes] R4  
Membrane attack complex [complement system] RS1  
Membrane cofactor protein [MCP] QR1, QR2  
Membrane depolarization V4  
Menaquinol D3, Q10  
Menaquinone [vitamin K2] D3, E10, Q10  
3-Mercaptopyruvate H4  
3-Mercatopyruvate sulfurtransferase 2.8.1.2 I4  
Mesaconate H6  
Mesaconate pathway HI6  
Mesobilirubinogen L6  
Mesophyll cell V10  
Messenger RNA [mRNA] M5  
Metarhodopsin V4  
Methacrylyl-CoA B10  
Methane A8, D5, M9, N9  
Methane monooxygenase 1.14.13.25 D5  
Methane oxidation D5, M9, N9  
Methanofuran [MFR] A8  
Methanogenesis A8, M9  
Methanol D5  
Methene-THF cyclohydrolase 3.5.4.9 A7  
5, 10-Methenyl-THF A7  
5, 10-Methenyltetrahydromethanopterin A8  
5, 10-Methenyltetrahydromethanopterin cyclohydrolase A8  
L-Methionine I3, N4, Q5  
Methionine adenosyltransferase 2.5.1.6 I3  
L-Methionine sulfoxide I3  
Methionine-S-oxide reductase 1.8.4.5 I3  
Methionine-tRNA ligase 6.1.1.10 I3  
Methionyl-tRNA formyltransferase 2.1.2.9 I3, N4, N5  
Methionyl-tRNA<sup>Met</sup> I3, N4  
Methionyl-tRNA<sup>Met</sup> I3, Q4  
2-Methoxyestradiol-17 $\beta$  L9  
2-Methoxyestrone L9  
3-Methyl-2-oxobutanoate dehydrogenase (lipoamide) 1.2.4.2 B9, B10  
[3-Methyl-2-oxobutanoate dehydrogenase] kinase 2.7.1.115 AB9  
[3-Methyl-2-oxobutanoate dehydrogenase] phosphatase 3.1.3.52 AB9  
3-Methyl-2-oxobutanoate hydroxymethyltransferase 2.1.2.11 AB10  
2-Methyl-3-hydroxybutyryl-CoA C9  
5-Methyl-tetrahydrofolate AB7, H3  
2-Methylacetoacetyl-CoA C9  
L-threo-3-Methylaspartate A9, H6  
Methylaspartate ammonia-lyase 4.3.1.2 H6  
Methylaspartate mutase 5.4.99.1 H6  
2-Methylbutyryl-CoA B9  
Methylcoenzyme M A8  
Methylcoenzyme-M reductase A8  
3-Methylcrotonyl-CoA B9  
Methylcrotonyl-CoA carboxylase C9  
5-Methylcytosine H3  
5, 10-Methylene-THF B7, K7, K8  
5, 10-Methylene-THF dehydrogenase (NADP<sup>+</sup>) 1.5.1.5 B7  
5, 10-Methylene-THF reductase (NADPH) 1.5.1.20 B7  
5, 10-Methylenetetrahydromethanopterin A8  
5, 10-Methylenetetrahydromethanopterin reductase A8  
5, 10-Methylenetetrahydromethanopterin dehydrogenase 1.5.99.9 A8  
trans-3-Methylglutaconyl-CoA C9  
Methylglyoxal H5  
N-Methylhistamine F2  
N-Methylhydantoin F7  
N-Methylhydantoinase 3.5.2.14 F7  
(S)-2-Methylmalate dehydratase 4.2.1.34 H6  
(S)-Methylmalonate semialdehyde C10  
Methylmalonate semialdehyde dehydrogenase (acylating) 1.2.1.27 C9  
(S) (=D)-Methylmalonyl-CoA I4  
(R) (=L)-Methylmalonyl-CoA I4  
Methylmalonyl-CoA carboxyltransferase 2.1.3.1 J4  
Methylmalonyl-CoA decarboxylase 4.1.1.41 J4  
Methylmalonyl-CoA epimerase 5.1.99.1 I4  
Methylmalonyl-CoA mutase 5.4.99.2 F5, I4  
Methylnicotinate H3  
Methylxaloacetate A9  
5-Methyltetrahydrofolate B8  
Methyltetrahydrofolate methyltransferase B8  
5-Methyltetrahydromethanopterin A8  
5-Methyltetrahydropteroyltriglutamate: homocysteine methyltransferase H3  
Mevalonate D9  
Mevalonate 5-phosphate D10  
Mevalonate 5-pyrophosphate D10  
Mevalonate kinase 2.7.1.36 D10  
MiaA O4  
Microtubule associated protein U4  
Mineralocorticoids H9  
Mineralocorticoid receptor U6  
Mitochondria O...Q9  
Mitochondrial myopathy O9, P9  
Mitomycin M8  
Molybdopterin L1  
1 (or 2)-Monoacylglycerol D8, T5  
Monoamine oxidase [amine oxidase (flavin-containing)] 1.4.3.4 H2, H5, I2  
Monoiodo-L-tyrosine G2  
Monoterpenes E10  
mRNA (guanine-N<sup>7</sup>-)-methyltransferase 2.1.1.56 PQ6  
mRNA (nucleoside-O<sup>2</sup>-)-methyltransferase 2.1.1.57 PQ6  
mRNA biosynthesis [eukaryotic] Q6, Q7  
mRNA guanylyltransferase 2.7.7.50 PQ6  
mRNA splicing OP5, OP6  
Mucopolipidose II S4  
cis-cis-Muconate E3  
Muconate cycloisomerase 5.5.1.1 E3  
Muconolactone  $\Delta$ -isomerase 5.3.3.4 F3  
Murein N2, NO3  
Muscarinic receptor V3  
Muscular contraction U4  
MutH, MutL, MutS [DNA repair enzymes] N7  
Mycosterols F9  
Myelin basic protein U4  
Myoglobin K5  
Myosin phosphate U5  
Myosin [light chain, heavy chain] U5  
Myosin-actin interactions U4, U5  
Myosin-light-chain kinase 2.7.1.117 U4, TU5  
Myxothiazol P9, S19

**N**

N1, N2, N3, N4 [iron-sulfur clusters in complex I of mitochondria] O9, QR9, QR10  
 Na<sup>+</sup>/K<sup>+</sup> transporting ATPase 3.6.1.37 S3  
 NAD(P)<sup>+</sup> nucleosidase 3.2.2.6 J1  
 NAD(P)<sup>+</sup> transhydrogenase 1.6.1.1 J1, S10  
 NAD(P)<sup>+</sup> transhydrogenase [complex I of mitochondria] 1.6.1.1 O9  
 NAD<sup>+</sup> J1+others  
 NAD<sup>+</sup> kinase 2.7.1.23 J1  
 NAD<sup>+</sup> synthase 6.3.1.5 J1  
 NADH J1+others  
 NADH dehydrogenase 1.6.5.3 M9, N9, O9, O10  
 NADH dehydrogenase (ubiquinone) 1.6.5.3 S10  
 NADH peroxidase 1.11.1.1 J1  
 NADP<sup>+</sup> J1+others  
 NADP<sup>+</sup> reductase (ferredoxin) T9  
 NADPH J4+others  
 NADPH-ferrihemoprotein reductase 1.6.2.4 TU6  
 Nalidixic acid O8  
 Neomycin M4, N4  
 Neurosporene E9  
 Neutrophilic chemotactic factor P2  
 Nicotinamide J1, O3, U3, U4, V3  
 Nicotinamide adenine dinucleotide [NAD<sup>+</sup>] J1+others  
 Nicotinamide adenine dinucleotide phosphate [NADP<sup>+</sup>] J1+others  
 Nicotinamide nucleotide adenyllyltransferase 2.7.7.1 J1  
 Nicotinamide nucleotide [NMN] J1  
 Nicotinamide riboside J1  
 Nicotinamide-nucleotide adenyllyltransferase 2.7.7.1 J1  
 Nicotinate H3, J1  
 Nicotinate methyltransferase 2.1.1.7 H4  
 Nicotinate nucleotide J2  
 Nicotinate phosphoribosyltransferase 2.4.2.12 J2  
 Nicotinate-nucleotide adenyllyltransferase 2.7.7.18 J1  
 Nicotinic acetylcholine receptor superfamily V3, V4  
 Nicotinic-acetylcholine receptor V4  
 Nitrate M10, N10  
 Nitrate reductase 1.7.99.4 M10  
 Nitric oxide M10  
 Nitric-oxide reductase 1.7.99.2 M10  
 Nitrite M10, N10  
 Nitrite reductase 1.7.99.3 M10

Nitrite:acceptor oxidoreductase N10  
 Nitrogen M10  
 Nitrogenase 1.18.6.1 G8  
 Nitrous oxide M10  
 Nitrous-oxide reductase 1.7.99.6 M10  
 Noncyclic electron flow ST9, ST10  
 L-Norepinephrine H2  
 Novobiocin O8  
 NtrB, NtrC [gene activator proteins] M5, M6  
 Nuclear location signal binding protein [NBP] S5, S6  
 Nuclear pore S5, S6  
 Nuclear protein import S5  
 Nuclear-protein kinase P7  
 Nucleocapsid [of retrovirus] PQ8  
 Nucleolus RS6, RS7  
 3'-Nucleosidase 3.1.3.6 K7, L7  
 Nucleoside deoxyribosyltransferase 2.4.6.2 I1, K8  
 Nucleoside-diphosphatase 3.6.1.6 G1, J8  
 Nucleoside-diphosphate kinase 2.7.4.6 H1, I1, I2, J7, J8, L7, L8  
 Nucleoside-phosphate kinase 2.7.4.4 K8  
 Nucleosome QR8  
 5'-Nucleotidase 3.1.3.5 G1, G2, I1, I2, J7, J8, L7  
 Nucleotide sugars B3  
 Nucleus O5...S8

**O**

O-specific side chain N2  
 Okazaki fragment O7  
 Oligomycin Q9  
 One carbon-pool B7, B8  
 Operator site MN7  
 Opsin V4  
 Oposonized antigen Q2  
 OriC [replication origin] M7  
 L-Ornithine G7  
 Ornithine carbamoyltransferase 2.1.3.3 G8  
 Ornithine decarboxylase 4.1.1.17 F7  
 Ornithine-oxoacid transaminase 2.6.1.13 H8  
 Orotate H8  
 Orotate phosphoribosyltransferase 2.4.2.10 I8  
 Orotidine 5'-phosphate I8  
 Orotidine-5'-phosphate decarboxylase 4.1.1.23 I8  
 Ouabain S3  
 Outer membrane [of gram-negative microorganisms] MN2  
 Outer nuclear membrane S5  
 Outer rod segment [of eye] V4  
 Oxalate C2, G6  
 Oxalate decarboxylase 4.1.1.2 G5  
 Oxalate-CoA transferase 2.8.3.2 G5  
 Oxaloacetate F5, J2, V10  
 Oxaloglutarate I3  
 Oxalosuccinate G6  
 Oxalyl-CoA G6  
 Oxalyl-CoA decarboxylase 4.1.1.8 G5  
 Oxidative phosphorylation H2  
 2-Oxo-3-acetamidocaproate K3  
 2-Oxo-3-deoxyoctulonic acid O3  
 2-Oxo-3-methylvalerate B9  
 2-Oxo-4-hydroxy-5-aminovalerate I8  
 2-Oxo-5-aminovalerate H8  
 3-Oxo-5 $\beta$ -steroid  $\Delta^4$ -dehydrogenase 1.3.99.6 F9, G9, G10, I10, L9, L10  
 2-Oxo-6-aminocaproate K3  
 3-Oxoacid-CoA transferase 2.8.3.5 F8  
 3-Oxoacyl-CoA E8  
 3-Oxoacyl-enzyme [acyl-carrier protein] E7  
 3-Oxoacyl-[acyl-carrier-protein] reductase 1.1.1.100 E7  
 3-Oxoacyl-[acyl-carrier-protein] synthase 2.3.1.41 E7  
 2-Oxo adipate I3  
 3-Oxo adipate F3  
 3-Oxo adipate CoA-transferase 2.8.3.6 F3  
 3-Oxo adipate enol-lactonase 3.1.1.24 F3  
 3-Oxo adipate enol-lactone F3  
 3-Oxo adipyl-CoA F3  
 19-Oxoandrost-4-ene-3, 17-dione J9  
 2-Oxobutyrate A9, H4  
 2-Oxoglutarate G6, J2  
 2-Oxoglutarate G6+frequently  
 2-Oxoglutarate decarboxylase [part of complex] 1.2.4.2 H6  
 2-Oxoglutarate dehydrogenase system 1.2.4.2 G5, G6  
 2-Oxoglutarate semialdehyde I8  
 2-Oxoglutarate-semialdehyde dehydrogenase I7  
 2-Oxoisocaproate B9  
 2-Oxoisovalerate B10  
 2-Oxopent-4-enoate F3  
 2-Oxopent-4-enoate hydratase F3  
 L-Oxosuccinamate F6  
 19-Oxotestosterone J9  
 3-Oxothreonate C2

Oxydative phosphorylation O...Q9, O...Q10  
 Oxyhemoglobin K5, T4

**P**

p21<sup>c-ras</sup> UV7  
 p33<sup>c-mos</sup> U7  
 p36 V6  
 p42 V6  
 p62/64 UV7, V6  
 p74<sup>c-raf</sup> U7  
 p190 UV7, V6  
 Palmitate D8  
 Palmitoyl-CoA B8, D8  
 Palmitoyl-CoA-enzyme palmitoyltransferase E7  
 Pantetheine C10  
 Pantetheine kinase 2.7.1.34 C10  
 Pantetheine-phosphate adenyllyltransferase 2.7.7.3 C10  
 (R)-Pantoate A10, G4  
 Pantothenase 3.5.1.22 B10  
 (R)-Pantothenate B10, G4  
 Pantothenate kinase 2.7.1.33 B10  
 Pantothenate- $\beta$ -alanine ligase 6.3.2.1 B10  
 Pantothenol A10  
 N-Pantothenoylcysteine BC10  
 Pantothenoylcysteine decarboxylase 4.1.1.30 C10  
*Paracoccus* O...Q9  
 Parkinsons disease O9  
 PCNA [proliferating cell nuclear antigen] S7, S8  
 Penicillin O3  
 Penicillin amidase 3.5.1.11 L3  
 Penicillin G L3  
 Pentosans B3  
 Pentose cycle C5  
 Pentose interconversions C3  
 Peptide deformylase M4  
 Peptidyl transferase 2.3.2.12 M3, P3  
 Perforin P2  
 Perinuclear cisternal space S6  
 Periplasmic space MN2, MN3  
 Peroxidase 1.11.1.7 K5, T6  
 Pertussis toxin V3  
 Phenylacetate L3  
 L-Phenylalanine F3  
 Phenylalanine 4-monooxygenase 1.14.16.1 F3  
 L-Phenylalanyl-tRNA F3  
 Phenylethanolamine N-methyltransferase 2.1.1.28 H2  
 Phenylpyruvate F3  
 Pheophytine K6, R9, S9  
 Phorbolster U3

Squares A...L refer to part 1, squares M...V to part 2.

Phosphatases (alkaline or acid) 3.1.3.1...2 C7, J7, L7  
 Phosphate acetyltransferase 2.3.1.8 C4  
 Phosphate butyryltransferase 2.3.1.19 L3  
 L-Phosphatidate D7, T3, U3  
 Phosphatidate cytidyltransferase 2.7.7.41 D7  
 Phosphatidate phosphatase 3.1.3.4 D8  
 Phosphatides CD7, CD8 (O<sup>3</sup>-Phosphatidyl)-L-serine C7  
 3-(3-Phosphatidyl)glycerol D7  
 3-(3-Phosphatidyl)glycerol 1-phosphate C7  
 1-Phosphatidyl-1D-*myo*-inositol C7, U3  
 1-Phosphatidyl-1D-*myo*-inositol 4, 5-bisphosphate T3  
 1-Phosphatidyl-1D-*myo*-inositol 4-phosphate T3  
 Phosphatidyl-N-methylethanolamine methyltransferase 2.1.1.71 C8  
 L-1-Phosphatidylethanolamine C7  
 Phosphatidylethanolamine methyltransferase 2.1.1.17 C8  
 1-Phosphatidylinositol kinase 2.7.1.67 U3, V5  
 1-Phosphatidylinositol-4,5-diphosphate V5, V6  
 1-Phosphatidylinositol-4-phosphate kinase 2.7.1.68 T3, V7  
 Phosphatidylserine decarboxylase 4.1.1.65 C7  
 7-Phospho-2-dehydro-3-deoxy-D-*arabino*-heptanoate D3  
 Phospho-2-dehydro-3-deoxy-heptanoate aldolase 4.2.1.15 D3  
 Phospho-2-dehydro-3-deoxygluconate aldolase 4.2.1.14 C4  
 2-Phospho-D-glycerate D5  
 3-Phospho-D-glycerate D5, U10  
 O-Phospho-L-homoserine H4  
 Phospho-N-acetylmuramoyl-pentapeptide transferase 2.7.8.13 N3  
 4'-Phospho-N-pantothenoyl cysteine C10  
 5-Phospho-β-D-ribosylamine C2  
 Phosphoacetylglucosamine mutase 5.4.2.3 D4  
 Phosphoadenylyl sulfatase 3.6.2.2 K4  
 3'-Phosphoadenylylsulfate reductase J4  
 3'-Phosphoadenylylsulfate [PAPS] JK3  
 O-Phosphocholine C8  
 Phosphocreatine U5  
 Phosphoenolpyruvate D3, E3, E4, E5, N3, V10  
 Phosphoenolpyruvate carboxykinase (ATP) 4.1.1.49 F5  
 Phosphoenolpyruvate carboxykinase (GTP) 4.1.1.32 F5  
 Phosphoenolpyruvate carboxykinase (pyrophosphate) 4.1.1.38 F5  
 Phosphoenolpyruvate carboxylase 4.1.1.31 F5, V10  
 Phosphoethanolamine C7  
 6-Phosphofructo-2-kinase 2.7.1.106 C6  
 Phosphofructokinase 2.7.1.11 C6  
 Phosphoglucokinase 2.7.1.10 B5  
 Phosphoglucomutase 5.4.2.2 B5, U9  
 D-6-Phosphogluconate C5  
 Phosphogluconate dehydratase 4.2.1.12 C4  
 Phosphogluconate dehydrogenase (decarboxylating) 1.1.1.44 C5  
 6-Phosphoglucono-1, 5-lactone C5  
 6-Phosphogluconolactonase 3.1.1.31 C5  
 D-3-Phosphoglycerate dehydrogenase 1.1.1.95 D6  
 Phosphoglycerate kinase 2.7.2.3 D5, U10  
 Phosphoglycerate mutase 5.4.2.1 D5  
 Phosphoglycolate T10  
 Phosphoglycolate phosphatase 3.1.3.18 T10  
 3-Phosphohydroxypyruvate D6  
 Phosphoketolase 4.1.2.9 C4  
 Phospholamban S5, U4  
 Phospholipase A<sub>1</sub> 3.1.1.32 D7, D8  
 Phospholipase A<sub>2</sub> 3.1.1.4 D7, D8, T5  
 Phospholipase C 3.1.4.3 D8, T3  
 Phospholipase C<sub>γ</sub> 3.1.4.3. T3, V6  
 Phospholipase D 3.1.4.4. D7, D8, V7  
 Phosphomevalonate kinase 2.7.4.2 D10  
 5-Phosphonoxy-L-lysine K3  
 4'-Phosphopantetheine C10  
 4'-Phosphopantothenate B10  
 Phosphopantothenate-cysteine ligase 6.3.2.5 C10  
 Phosphopantothenoylcysteine decarboxylase 4.1.1.36 C10  
 N-(5'-Phosphoribosyl)-anthranilate G3  
 5'-Phosphoribosyl-4-(N-succinocarboxamide)-5-aminoimidazole E2  
 5'-Phosphoribosyl-4-carboxy-5-imidazole E2  
 5'-Phosphoribosyl-5-amino-4-imidazole carboxamide [AICAR] F2  
 5'-Phosphoribosyl-5-aminoimidazole [AIR] E2  
 5'-Phosphoribosyl-5-formamido-4-imidazole carboxamide A7, F2  
 Phosphoribosyl-AMP D2  
 Phosphoribosyl-AMP cyclohydrolase 3.5.4.19 D2  
 Phosphoribosyl-ATP D2  
 Phosphoribosyl-ATP pyrophosphatase 3.6.1.31 D2  
 Phosphoribosyl-formylglycinamide cycloligase 6.3.3.1 E2  
 5'-Phosphoribosyl-N-formylglycinamide [FGAR] A7, D2  
 5'-Phosphoribosyl-N-formylglycinamide [FGAM] E2  
 Phosphoribosylamine-glycine ligase 6.3.4.13 D2  
 Phosphoribosylaminoimidazolecarboxamide carboxylase 4.1.1.21 E2  
 Phosphoribosylaminoimidazolecarboxamide formyltransferase 2.1.2.3 A7, F2  
 Phosphoribosylaminoimidazolesuccinocarboxamide synthase 6.3.2.6 E2  
 Phosphoribosylanthranilate isomerase G3  
 Phosphoribosylformimino-AICAR phosphate D2  
 Phosphoribosylformimino-AICAR-phosphate isomerase 5.3.1.16 D2  
 Phosphoribosylformylglycinamide synthase 6.3.5.3 D2  
 Phosphoribosylglycinamide formyltransferase 2.1.2.2 A7, D2  
 5'-Phosphoribosylglycinamide [GAR] A7, D2  
 α-D-5-Phosphoribosylpyrophosphate [PRPP] C2, F3, I8  
 Phosphoribulokinase 2.7.1.19 U10  
 Phosphoribulosyl-formimino-AICAR phosphate E2  
 Phosphorylase kinase 2.7.1.38 A5, A6, U4, U6  
 Phosphorylase phosphatase 3.1.3.17 A5, U6  
 Phosphorylase [a, b] 2.4.1.1 A5, U6  
 Phosphorylcholine cytidyltransferase 2.7.7.15 C8  
 Phosphorylethanolamine cytidyltransferase 2.7.7.14 C7  
 O-Phosphoserine D6  
 Phosphoserine phosphatase 3.1.3.3 C6  
 Phosphoserine transaminase 2.6.1.52 D6  
 3-Phosphoshikimate 1-carboxyvinyltransferase E3  
 Phosphotransferase system [enzymes I, II, III] N3  
 Photoreactivation [of DNA] Q8  
 Photorespiration T10  
 Photosynthesis R...T9, R...T10  
 Photosynthetic reaction center [purple bacteria] S10  
 Photosystems I, II [chloroplasts] S9  
 Phycocyanobilin K5  
 Phylloquinol D3, H7  
 Phylloquinone epoxide I7  
 Phylloquinone monooxygenase 1.14.99.20 H17  
 Phylloquinone [vitamin K<sub>1</sub>] D3, E10  
 Physostigmin V4  
 3-Phytase T4, T5  
 6-Phytase 3.1.3.26 T4, T5  
 Phytoene E10  
 Phytol K6  
 Phytosterols F9  
 Phytyl pyrophosphate E10, K6  
 Picolinate J2  
 Piercidin A O9  
 L-Pipecolate K3  
 Pipecolate dehydrogenase K3  
 Δ<sup>1</sup>-Piperideine-2, 6-dicarboxylate H3  
 Δ<sup>1</sup>-Piperideine-2-carboxylate reductase 1.5.1.21 K3  
 Δ<sup>6</sup>-Piperideine-2-L-carboxylate K3, J3  
 Plasma kallikrein [KK] 3.4.21.34 T1, T2  
 Plasma prekallikrein [PK] S1, T1, T2  
 Plasmin 3.4.21.7 UV2  
 Plasminogen activator inhibitor 1, 2, 3 [PAI-1, 2, 3] UV2  
 Plasminogen [PLG] U2  
 Plastocyanine R10, S9  
 Plastoquinol-plastocyanin complex [cytochrome b-f complex] S9  
 Plastoquinone G3, RS9, R10  
 Platelet activating factor [PAF] P2, V2  
 Platelet activation UV2  
 Platelet derived growth factor [PDGF] V7  
 Platelet-derived-growth-factor [PDGF] receptor T3, U4, U7, V6, V7  
 Platelet factor 3 [PF 3, microvesicles] V2  
 Polyadenylated mRNA Q5  
 Polyadenylated pre-mRNA Q5  
 Polydeoxyribonucleotide synthase (NAD<sup>+</sup>) [DNA ligase] 6.5.1.2 O7, QR6, S7



- Polyenoic acids D7  
 Polynucleotide adenyltransferase 2.7.7.19 Q5, Q6  
 Polypeptide N-acetylgalactosaminyltransferase 2.4.1.41 QR4  
 Polyperforin P2  
 Polyprenyl *cis*-transferases 2.5.1.x E10  
 Polyprenyl *trans*-transferases 2.5.1.x E10  
 2-Polyprenylphenol E3  
 Polyribonucleotide nucleotidyl transferase 2.7.7.8 H1, H2, JK7, JK8  
 Polysaccharides A5  
 Porphobilinogen H5  
 Porphobilinogen deaminase 4.3.1.8 H5  
 Porphobilinogen synthase 4.2.1.24 H5  
 Porphyrins IJ5  
 Potassium channel V3  
 Pre-tRNA QR6  
 Precorrin 2 I5  
 Precorrin 3 I6  
 5 $\beta$ -Pregnane-3, 20-dione G10  
 Pregnane-3, 20-dione G10  
 Pregnanediol F10  
 Pregnenolone H9  
 Prephenate E3  
 Prephenate dehydratase 4.2.1.51 E3  
 Prephenate dehydrogenase 1.3.1.12...13 E3  
 Preprotein translocase M3  
 Preuroporphyrinogen [hydroxymethylbilane] H5  
 Pribnow-box M7  
 Primase NO8, R8, S7, S8  
 Primosome N8  
 Proaccelerin [factor V/Va] V1, V2  
 Procollagen galactosyltransferase 2.4.1.50 K3  
 Procollagen(5-galactosyloxy)-L-lysine K3  
 Procollagen-L-*erythro*-5-hydroxy-L-lysine K3  
 Procollagen-lysine, 2-oxoglutarate 5-dioxygenase 1.14.11.4 K3  
 Procollagen-proline, 2-oxoglutarate 4-dioxygenase 1.14.11.2 H7  
 Proconvertin/convertin [factor VII/VIIa] 3.4.21.21 UV1  
 Profilin T3  
 Progesterone H9  
 Progesterone receptor U6  
 D-Proline H8  
 L-Proline H7  
 L-Proline dehydrogenase 1.5.99.8 H7, HI7  
 Proline racemase 5.1.1.4 H7  
 D-Proline reductase (dithiol) 1.4.4.1 H8  
 Promotion [of transcription] M5, PQ7  
 Promotor region Q7  
 1, 2-Propanediol D6  
 2-Propanol L3  
 2-Propanol dehydrogenase (NAD<sup>+</sup>) L3  
 Properdin QR1  
 Propionate J4  
 Propionate-CoA ligase 6.2.1.17 J4  
 Propionyl-CoA C9, J4, K10  
 Propionyl-CoA carboxylase 6.4.1.3 J4  
 Propionyladenylate J4  
 Prostacyclin synthase 5.3.99.4 T6  
 Prostaglandin D<sub>2</sub> P1, T6, U3  
 Prostaglandin E<sub>1</sub> U3  
 Prostaglandin E<sub>2</sub> U3, U6  
 Prostaglandin F<sub>2 $\alpha$</sub>  TU7  
 Prostaglandin G<sub>2</sub> T6  
 Prostaglandin H<sub>2</sub> TU6  
 Prostaglandin I<sub>2</sub> [prostacyclin] T6, U3  
 Prostaglandin synthase 1.14.99.1 TU6  
 Prostaglandin-D<sub>2</sub> 11-ketoreductase 1.1.1.188 TU7  
 Prostaglandin-E<sub>2</sub> 9-ketoreductase 1.1.1.189 U7  
 Prostaglandin-H<sub>2</sub> D-isomerase 5.3.99.2 T6  
 Prostaglandin-H<sub>2</sub> E-isomerase 5.3.99.3 U6  
 Prostaglandins D7, TU6, TU7  
 Protease nexin 2 [PN-2] T1  
 Protein A [bacteria] O2  
 Protein C [PC, coagulation] V1, V2  
 Protein C<sub>a</sub> inhibitor [PCI, PAI-3, coagulation] V1  
 Protein export [in eubacteria] M2, M3  
 Protein folding, correction S4, S5  
 Protein kinase A 2.7.1.37 A6, E5, F6, D7, S5, P7, T5, U3, U6, U7, V7  
 Protein kinase B U5  
 Protein kinase C 2.7.1.37 S5, Q7, U3, U7, V5, V6  
 Protein kinase (calmodulin dependent) 2.7.1.37 P7, T5  
 Protein kinase G 2.7.1.37 UV5  
 Protein kinase (insulin stimulated) 2.7.1.37 V5, V6  
 Protein phosphatase 2A, 2B U5  
 Protein S [coagulation] V1  
 Protein-tyrosine kinase 2.7.1.112 V5, V6, V7  
 $\alpha$ 1-Proteinase inhibitor [ $\alpha$ 1-Pi] T1  
 Proteoglycans Q3  
 Protochlorophyllide reductase 1.3.1.33 K6  
 Protoheme J5  
 Protoporphyrin IX J5  
 Protoporphyrinogen IX J5  
 Protoporphyrinogen oxidase 1.3.3.4 J5  
 Pseudomonic acid N4  
 Pseudouridine O4  
 Pseudouridylate synthase O4  
 Psychosine C8  
 PTA factor [plasma-thrombin antecedent, factor XI / XIa] 3.4.21.27 ST1  
 Pterine biosynthesis KL1, KL2  
 Pulvomycin N3  
 Purine biosynthesis D2...F2  
 Purine nucleotidase 3.2.2.1 G1  
 Purine-nucleoside phosphorylase 2.4.2.1 G1, I1  
 Purinedeoynucleoside 3'-phosphate L7  
 Purinedeoynucleoside 5'-phosphate L7  
 Purinenucleoside 3'-phosphate K7  
 Purinenucleoside 5'-phosphate K7  
 Puromycin M4, R4  
 Purple bacteria R...T10  
 Putrescine F7  
 Pyrimidine biosynthesis J...L7, J...L8  
 Pyrimidine-5'-nucleotide nucleosidase 3.2.2.10 J7, K8  
 Pyrimidinedeoynucleoside 3'-phosphate L7  
 Pyrimidinedeoynucleoside 5'-phosphate L7  
 Pyrimidinenucleoside 3'-phosphate K7  
 Pyrimidinenucleoside 5'-phosphate J7  
 Pyrophosphatase [see inorganic pyrophosphatase] 3.6.1.1 J4, S8  
 Pyrrole-2-carboxylate I8  
 1-Pyrroline-2-carboxylate H8  
 Pyrroline-2-carboxylate reductase 1.5.1.1 H7, I7  
 L-1-Pyrroline-3-hydroxy-5-carboxylate I7  
 1-Pyrroline-4-hydroxy-2-carboxylate I8  
 1-Pyrroline-4-hydroxy-2-carboxylate deaminase 3.5.4.22 I8  
 L-1-Pyrroline-5-carboxylate H7  
 1-Pyrroline-5-carboxylate dehydrogenase 1.5.1.12 H7, I7  
 Pyrroline-5-carboxylate reductase 1.5.1.2 H7, I7  
 Pyruvate E5+frequently  
 Pyruvate carboxylase 6.4.1.1 F5  
 Pyruvate decarboxylase 4.1.1.1 E6  
 Pyruvate dehydrogenase (cytochrome) 1.2.2.2 E6  
 Pyruvate dehydrogenase (lipoamide) 1.2.4.1 E5  
 [Pyruvate dehydrogenase (lipoamide)] kinase 2.7.1.99 E6  
 [Pyruvate dehydrogenase (lipoamide)] phosphatase 3.1.3.43 E6  
 Pyruvate kinase 2.7.1.40 E5  
 [Pyruvate kinase] phosphatase 3.1.3.49 E5  
 Pyruvate synthase 1.2.7.1 E5, K4  
 Pyruvate, orthophosphate dikinase 2.7.9.1 V10  
 6(*R*)-Pyruvoyltetrahydropterin K1  
 6-Pyruvoyltetrahydropterin reductase 1.1.1.220 K1  
**Q**  
 Quinate D3  
 Quinate dehydrogenase 1.1.1.24 D3  
 Quinolinate J2  
 Quinolinate nucleotide J2  
 Quinolinate phosphoribosyltransferase (decarboxylating) 2.4.2.19 J2  
 Quinone pool M9, N9, O9, O10, S9, S10  
**R**  
 Raf V7  
 Ras V7  
 Raffinose B4  
 Receptor endocytosis S2.S3  
 Receptor for von-Willebrand-factor [platelet surface, GP Ib/IX] U1  
 Receptors coupled to trimeric G proteins UV3, UV4  
 Receptors with guanylate cyclase activity V5  
 Receptors with tyrosine kinase activity V5, V6, V7  
 Redox potentials MN9, MN10, QR9, QR10  
 Regulation [of transcription] PQ7  
 Replicon [DNA] R8  
 Repression [of transcription] N6  
 Respiratory chain O...Q9, O...Q10  
 11-*cis*-Retinal D9, T10, V4  
*all-trans*-Retinal V4, T10  
 Retinal dehydrogenase 1.2.1.36 D9  
 Retinal isomerase 5.2.1.3 D9, V4  
 Retinoate D9  
 Retinoic acid receptor U6  
 Retinol D9

Squares A...L refer to part 1, squares M...V to part 2.

Retinol dehydrogenase 1.1.1.105 D9  
Retinyl palmitate D9  
Retinyl-palmitate esterase 3.1.1.21 D9  
Retrovirus PQ8  
Reverse electron flow O9, O10, S10  
Reverse transcriptase [see RNA-directed DNA polymerase] 2.7.7.49 Q8  
RF I, RF II, RF III [eubacterial release factors] M4  
RF-A [replication factor] P8, R8  
RF-C [replication factor] S7, S8  
Rhamnoside B3  
*Rhodopseudomonas sphaeroides* R...T10  
Rhodopsin V4  
Rhodopsin phosphate V4  
 $\alpha$ -Ribazole I6  
D-Ribitol C4, O3  
Ribitol dehydrogenase 1.1.1.56 C4  
Ribokinase 2.7.1.47 C4  
Ribonuclease III 3.1.26.3 N6  
Ribonuclease P 3.1.26.5 O6  
Ribonucleases [general] 3.1.26.x; 3.1.27.x K7, M5, O5  
Ribonucleic acid H1, H2, K7, K8  
Ribonucleoside-diphosphate reductase 1.17.4.1 HI1, HI2, JK7, JK8  
Ribonucleoside-triphosphate reductase 1.17.4.2 HI1, HI2, JK7, JK8  
Ribophorin QR4  
D-Ribose C4, J7, J8, N8  
D-Ribose 1-phosphate J7, J8  
D-Ribose 5-phosphate U10  
Ribose-5-phosphate isomerase 5.3.1.6 C5, U10  
Ribose-phosphate pyrophosphokinase 2.7.6.1 C2, H8  
20S, 32S Ribosomal intermediates RS6  
Ribosomal proteins NO5, RS6  
30S Ribosomal subunit M5, N5  
40S Ribosomal subunit P5, R6, S4  
50S Ribosomal subunit MN4  
60S Ribosomal subunit P5, RS5, R6, S4  
Ribosome receptor QR4  
Ribosomes MN3, MN4, OP3, OP3, S5  
Ribothymidine O4  
D-Ribulokinase 2.7.1.16 C3, C4  
L-Ribulose C3  
D-Ribulose C4  
D-Ribulose 1, 5-bisphosphate U10  
D-Ribulose 5-phosphate C5, U10  
L-Ribulose 5-phosphate C3  
Ribulose-bisphosphate carboxylase 4.1.1.39 U10  
Ribulose-phosphate 3-epimerase 5.1.3.1 C3, U10  
L-Ribulose-phosphate 4-epimerase 5.1.3.4 C4  
Rieske iron-sulfur center P9, QR10, S9, S10  
Rifampicin M6  
RNA-directed DNA polymerase [reverse transcriptase] 2.7.7.49 Q8  
RNA-directed RNA polymerase 2.7.7.48 JK7, JK8, H1, H2  
Rod segment [eye] V4  
Rotenone O9  
rProteins [ribosomal proteins] NO5, RS6  
5S, 16S, 23S rRNA NO6  
5S, 5.8S, 18S, 28S rRNA RS6  
rRNA biosynthesis [eukaryotic] RS6, RS7  
45S rRNA precursor [primary transcript] R6  
Rubber (*all-cis*) D10  
Rubber *cis*-polyprenyl-*cis*-transferase 2.5.1.20 D10  
Rubredoxin D8  
Rusticyanin N10  
Rutin B3

**S**  
S1, S2, S3 [iron-sulfur clusters in complex II of mitochondria] O9, QR10  
Saccharopine J3  
Saccharopine dehydrogenase (NAD<sup>+</sup>, L-glutamate-forming) 1.5.1.9 J3  
Saccharopine dehydrogenase (NAD<sup>+</sup>, L-lysine-forming) 1.5.1.7 J3  
Saccharopine dehydrogenase (NADP<sup>+</sup>, L-glutamate-forming) 1.5.1.10 J3  
Saccharopine dehydrogenase (NADP<sup>+</sup>, L-lysine forming) 1.5.1.8 J3  
Sarcoplasmic reticulum S4, S5  
Sarcosine B7, F7  
Sarcosine dehydrogenase 1.5.99.1 B7  
Schardinger dextrin A5  
Scymnol sulfate K10  
SecA, SecB, SecE, SecY [bacterial protein export] M3  
Secretion [of (glyco-)proteins] R3, S3  
D-Seduheptulose 1, 7-bisphosphate D5, U10  
D-Seduheptulose 7-phosphate C5, U10  
Seduheptulose bisphosphatase 3.1.3.37 U10  
Sepiapterin reductase 1.1.1.153 K1  
L-Serine B7, B8, H3  
L-Serine dehydratase 4.2.1.13 B7, I4  
Serine palmitoyltransferase 2.3.1.50 B8  
Serine-glyoxylate transaminase 2.6.1.45 B7  
Serotonin I2, V3  
Serotonin receptor V3  
Sesquiterpenes E10  
SHC V5, V6  
Shikimate D3  
Shikimate 3-phosphate D3  
Shikimate dehydrogenase 1.1.1.25 D3  
Shikimate kinase 2.7.1.71 D3  
Sialate F3  
Siderochrome J5  
Signal peptide M3, QR4  
Signal recognition particle [SRP] QR4  
Signal-peptidase M3, R4  
Single strand binding protein M8, N7  
Siroheme I4, J5  
Site-specific deoxyribonucleases types I, II, III 3.1.21.3...5 M2  
Slow reacting substance of anaphylaxis [SRS-A] P1  
snRNP [see U1...] P5, P6  
Sodium channel U4, V4, V5  
Soluble immune complex R2  
Somatic recombination of DNA P7  
D-Sorbitol C6  
Sp1 [stimulatory protein 1] P7  
Spectinomycin M4  
Spectrin R3  
Spermidine F7  
Spermine F7  
Sphinganine C8  
Sphingomyelin C8  
Sphingomyelin phosphodiesterase 3.1.4.12 C8  
Sphingosine C8  
Sphingosine acyltransferase 2.3.1.24 C8  
Sphingosine  $\beta$ -galactosyltransferase 2.4.1.23 B8  
Spliceosome OP5, OP6  
Squalene E10  
(S)-Squalene 2, 3-epoxide F10  
Squalene monooxygenase 1.14.99.7 E10  
SRF [serum responsive factor] Q7  
SRP receptor [docking protein] R4  
Starch V9  
Starch synthase 2.4.1.21 B5, V9  
I-Stercobilin L6  
I-Stercobilinogen L6  
Steroid  $\Delta$ -isomerase 5.3.3.1 H9, I9, J10  
Steroid 11 $\beta$ -monooxygenase 1.14.15.4 G9, H9, I9  
Steroid 16 $\alpha$ -hydroxylase I10, K9, K10  
Steroid 17 $\alpha$ -monooxygenase 1.14.99.9 H9, H10, I9  
Steroid 19-hydroxylase J9  
Steroid 21-monooxygenase 1.14.99.10 H9, I9  
Steroid hormones OP7, U6, V6  
Steroid receptor superfamily U6  
Steroid receptors O7, U4  
Seryl-sulfatase 3.1.6.2 I10  
Stigmasterol F9  
Stop-transfer sequence R4  
Streptogramin M3  
Streptolydigin M5  
Stuart-Prower factor [factor X / Xa] 3.4.21.6 V1, V2  
Succinate F3, F8, G4, G5, H7, I3, J4, M9, MN10, O9, O10, Q10, R10, S10  
Succinate dehydrogenase (ubiquinone) 1.3.5.1 G5, M9, O9, O10, S10  
Succinate dehydrogenase (ubiquinone) [complex II of mitochondria] 1.3.5.1 P9  
Succinate-CoA ligase (ADP-forming) 6.2.1.5 G5  
Succinate-CoA ligase (GDP-forming) 6.2.1.4 G5  
Succinate-propionate CoA transferase J4  
Succinate-semialdehyde H5  
Succinate-semialdehyde dehydrogenase (NAD(P)<sup>+</sup>) 1.2.1.16 H5  
Succinyldiaminopimelate succinylase 3.5.1.18 I3  
N-Succinyl-2-amino-6-oxopimelate I3  
Succinyl-CoA G3, G5, I3, J4  
Succinyl-CoA hydrolase 3.1.2.3 G5  
Succinyl-diaminopimelate transaminase 2.6.1.17 I3  
O-Succinyl-L-homoserine G4  
N-Succinyl-L-2, 5-diaminopimelate I3  
2-Succinylbenzoate E3  
O-Succinylhomoserine (thiol)-lyase 4.2.99.9 G3, G4

- Sucrose A4  
 Sucrose 6-phosphate A4, V9  
 Sucrose phosphorylase 2.4.1.7 A4  
 Sucrose-phosphate synthase 2.4.1.14 A4  
 Sugar nucleotide transport system ST4  
 Sulfate J4, M10, N10  
 Sulfate adenylyltransferase [ATP sulfurylase] 2.7.7.4 J4, M10, N10  
 Sulfide M9, N9  
 Sulfide dehydrogenase N9  
 3-Sulfinoaniline I4  
 Sulfinoaniline decarboxylase 4.1.1.29 I4  
 3-Sulfinylpyruvate I4  
 Sulfite J4  
 Sulfite dehydrogenase 1.8.2.1 J4, N9  
 Sulfite oxidase 1.8.3.1 J4  
 Sulfite reductase 1.8.1.2 M9  
 Sulfite reductase (NADPH) 1.8.99.1 I4  
 Sulfite, bisulfite M9, N9  
 Sulfur N9  
 Sulfur dioxygenase 1.13.11.18 N9  
 Sulfur metabolism I...K4  
 SV 40 circular DNA duplex Q8  
 Synapsin I T5
- T**  
 T-antigen [of SV 40] R8  
 T-cell receptor [CD3] O2, Q2, Q3, U4  
 T-lymphocyte O...Q2, PQ3  
 Tagetitoxin Q6, R6, R7, S6  
 Tartronate semialdehyde A2, D5  
 Tartronate semialdehyde synthase 4.1.1.47 D5  
 TATA-box Q7  
 Taurine I4, K10  
 Taurocholate K10  
 Teichoic acid N2  
 Telomerase R7, R8  
 Telomere synthesis RS7, RS8  
 Terminal O- and N-glycosylations R3  
 Testosterone J9  
 Testosterone glucuronide J10  
 Tetracycline N4  
 6(R)-5, 6, 7, 8-Tetrahydrobiopterin F3, G2, H2, K1  
 Tetrahydrocorticosterone G9  
 6(S)-5, 6, 7, 8-Tetrahydrofolate [THF] A7, D2, F2, G2, I3, K7  
 5, 6, 7, 8-Tetrahydromethanopterin [THMPT] A8, K2
- 3 $\alpha$ , 7 $\alpha$ , 12 $\alpha$ , 26-Tetrahydroxy-5 $\beta$ -cholestane J10  
 3 $\alpha$ , 7 $\alpha$ , 12 $\alpha$ , 24 $\zeta$ -Tetrahydroxy-5 $\beta$ -cholestanoyl-CoA J10  
 TF [tissue factor] UV1  
 TFIB, TFIC [transcription factors] RS6, RS7  
 TFIIA, TFIIB, TFIID, TFIIE, TFIIF, TFIIG, TFIIH, TFIIS, [transcription factors] Q6, Q7  
 TFIIIA, TFIIB, TFIIC [transcription factors] QR6, QR7, S6  
 Thick filament [muscle] U5  
 Thin filament [muscle] U5  
 Thiocysteine I4  
 Thioredoxin HI1, HI2, K7, K8, J4, T9  
 Thioredoxin reductase (ferredoxin) T9  
 Thioredoxin reductase (NADPH) 1.6.4.5 HI1, HI2, K7, K8  
 Thiosulfate sulfotransferase 2.8.1.1 H4  
 L-Threonate C2  
 L-Threonate dehydrogenase 1.1.1.129 C2  
 L-Threonine A9, H4  
 L-Threonine 3-dehydrogenase 1.1.1.103 H4  
 Threonine aldolase 4.1.2.5 H4  
 Threonine dehydratase 4.2.1.16 A9, H4  
 Threonine synthase 4.2.99.9 H4  
 Thrombin T6  
 Thrombin receptor [platelet surface, GP V] U2  
 Thrombin [factor IIa] 3.4.21.5 V2  
 Thrombomodulin [TM] V1, V2  
 Thrombospondin receptor [platelet surface, GP IIIB] UV2  
 Thrombospondin [TSP] V2  
 Thromboxane A<sub>2</sub> P1, U6  
 Thromboxane B<sub>2</sub> U7  
 Thromboxane synthase 5.3.99.5 U6  
 Thymidine K8  
 Thymidine 5'-diphosphate [dTDP] L7  
 Thymidine 5'-phosphate [dTMP] K7  
 Thymidine 5'-triphosphate [dTTP] L7  
 Thymidine dimer Q8  
 Thymidine kinase 2.7.1.21 K8  
 Thymidine phosphorylase 2.4.2.4 K8  
 Thymidine triphosphatase 3.6.1.39 L8  
 Thymidylate synthase 2.1.1.45 K8  
 Thymine L8  
 Thyroid-hormone receptor U6
- L-Thyroxine [T4] H2  
 Tiamulin M3  
 Tiglyl-CoA B9  
 Tissue factor pathway [of blood coagulation] UV1  
 Tissue-type plasminogen activator [single chain-, two chain=sctPA, tctPA] 3.4.21.31 U2  
 Tocopherol E10, G3  
 Topoisomerase (TOPO) QR6, RS78  
 Transaldolase 2.2.1.2 C5  
 Transcription [eubacterial] MN5, MN6, MN7  
 Transcription [for eukaryotic mRNA] Q5, Q6, Q7  
 Transcription [for eukaryotic rRNA] RS6, RS7  
 Transcription [for eukaryotic tRNA] QR6, QR7  
 Transducin UV4  
 Transfer RNA [tRNA] O5, O6, Q5, R6, R7  
 Transfer to outer membrane Q3  
 Transferrin reductase 1.16.1.2 J5  
 Transglycosylase [murein synthesis] O3  
 Transketolase 2.2.1.1 C5, U9, U10  
 Translation [eukaryotic] O...Q4, O...Q5  
 Translation [in eubacteria] M4  
 Transpeptidase [murein synthesis] O3  
 Transport vesicle S3, S4  
 Triacylglycerol D8, S2  
 Triacylglycerol lipase 3.1.1.3 D8, U4  
 Triglyceride [see triacylglycerol] D8, S2  
 3 $\alpha$ , 11 $\beta$ , 21-Trihydroxy-20-oxo-5 $\beta$ -pregnan-18-al F9  
 3 $\alpha$ , 7 $\alpha$ , 12 $\alpha$ -Trihydroxy-5 $\beta$ -cholestane I10  
 3 $\alpha$ , 7 $\alpha$ , 12 $\alpha$ -Trihydroxy-5 $\beta$ -cholestanolate J10  
 3 $\alpha$ , 20 $\alpha$ , 21-Trihydroxy-5 $\beta$ -pregnan-11-one F9  
 11 $\beta$ , 17 $\alpha$ , 21-Trihydroxy-5 $\beta$ -pregnane-3, 20-dione J9  
 3, 5, 3'-Triiodothyronine [T3] H2  
 Trikinase 2.7.1.28 D6  
 Triose-phosphate isomerase 5.3.1.1 D6, U9  
 tRNA (uracil-5-)-methyltransferase 2.1.1.35 O4  
 tRNA adenylyltransferase 2.7.7.25 O5, O6  
 tRNA biosynthesis [eukaryotic] QR6, QR7
- tRNA cytidylyltransferase 2.7.7.21 O5, O6  
 tRNA modifications O4, QR6  
 tRNA splicing QR6  
 tRNA<sup>aminoacid</sup> [general] M4, N5, Q5  
 tRNA<sup>Met</sup> M4, N5  
 tRNA<sup>Met</sup> Q5  
 Tropomyosin U5  
 Troponin [C, I, T] U5  
 trp Repressor N6  
 Tryptamine I2  
 Tryptophan N6  
 Tryptophan 2, 3-dioxygenase 1.13.11.11 J2  
 Tryptophan 5-monooxygenase 1.14.16.4 H2, U4  
 Tryptophan synthase 4.2.1.20 H3  
 Tryptophan transaminase 2.6.1.27 H2  
 Tryptophanase 4.1.99.1 H3  
 L-Tryptophanyl-tRNA H3  
 TTF-I S6  
 Tuberculostearate D7  
 d-Tubocurarin V4  
 Tumor necrosis factor  $\alpha$  [TNF- $\alpha$ ] O1  
 Tumor necrosis factor  $\beta$  [TNF- $\beta$ ] O1  
 Tylosin M3  
 Tyrosine protein kinase p56<sup>lck</sup> Q3  
 L-Tyrosine F3  
 Tyrosine 3-monooxygenase 1.14.16.2 G2, U4  
 Tyrosine 5-monooxygenase T5  
 Tyrosine transaminase 2.6.1.5 F3  
 L-Tyrosyl-tRNA F3
- U**  
 U1, U2, U3, U4, U5, U6 [snRNP, small nuclear ribonucleoprotein particles] P5, P6  
 UBF R6, R7  
 Ubiquinol, ubiquinone D3, E10, M9, N9, MN10, OP9, O10, P10, QR10, S10  
 Ubiquinol-cytochrome-c reductase [complex III of mitochondria] 1.10.2.2 P9  
 Ubiquinol-cytochrome-c reductase [cytochrome bc complex] 1.10.2.2 S10  
 UDP-arabinose 4-epimerase 5.1.3.5 B3  
 UDP-D-galactose B4, C8  
 UDP-D-galacturonate B3  
 UDP-D-glucose B5, C8  
 UDP-D-glucuronate B3, L5, K10  
 UDP-L-arabinose B3  
 UDP-L-rhamnose B5  
 UDP-N-acetyl-D-glucosamine E4



Squares A...L refer to part 1, squares M...V to part 2.

UDP-N-acetylgalactosamine E4	Undecaprenyl diphosphatase 3.6.1.27 N3	Urokinase-type plasminogen activator [single chain-, two chain- =scuPA, tcuPA] 3.4.21.31 U2	Vitamin E [tocopherol] E10, G3
UDP-N-acetylglucosamine 1-carboxyvinyltransferase 2.5.1.7 E4	Undecaprenyl phosphates N3	Uronolactonase 3.1.1.19 A2	Vitamin K UV1, V2
UDP-N-acetylglucosamine 2-epimerase 5.1.3.14 E4	Unspecific monooxygenase 1.14.14.1 TU6	Uroporphyrin I I5	Vitamin K <sub>1</sub> [phyloquinone] D3, E10
UDP-N-acetylglucosamine 4-epimerase 5.1.3.7 E4	Uracil J8, N4, O4	Uroporphyrin III I5	Vitamin K <sub>2</sub> [menaquinone] D3
UDP-N-acetylglucosamine pyrophosphorylase 2.7.7.23 D4	Uracil dehydrogenase 1.1.99.19 J8, L8	Uroporphyrinogen decarboxylase 4.1.1.37 I5	Vitamin-D receptor U6
UDP-N-acetylglucosamine-dolichylphosphate N-acetylglucosamine phosphotransferase 2.7.8.15 R5	Uracil phosphoribosyltransferase 2.4.2.9 J8	Uroporphyrinogen I H5	Vitronectin [S-protein] RS1, RS2, T2
UDP-N-acetylglucosamine-lysosomal-enzyme N-acetylglucosaminophosphotransferase 2.7.8.17 S4	Urate H8	Uroporphyrinogen III I5	Voltage-gated calcium channel V4
UDP-N-acetylmuramate F4, O3	Urate 3-ribonucleoside H1	Uroporphyrinogen-III methyltransferase I5	Voltage-gated sodium channel V4
UDP-N-acetylmuramate dehydrogenase 1.1.1.158 E4	Urate oxidase 1.7.3.3 H1	Uroporphyrinogen-III synthase 4.2.1.75 I5	von Willebrand factor [vWF] U1, V1
UDP-N-acetylmuramate-alanine ligase 6.3.2.8 O4	Urate-ribonucleotide phosphorylase 2.4.2.16 H1	UTPGlucose-1-phosphate uridylyltransferase 2.7.7.9 B5	<b>W</b>
UDP-N-acetylmuramoyl-L-alanyl-D-glutamate-lysine ligase 6.3.2.7 O4	Urea G8, K8	UTPHexose-1-phosphate uridylyltransferase 2.7.7.10 B4	<i>Wolinella succinogenes</i> Q10
UDP-N-acetylmuramoylalanine-D-glutamate ligase 6.3.2.9 O4	Urea cycle G8	UvrA, UvrB, UvrC, UvrD [DNA repair enzymes] N7	<b>X</b>
UDP-N-actylglucosamine pyrophosphorylase 2.7.7.23 D4	Urease 3.5.1.5 G8		Xanthine G1
UDP- $\alpha$ -D-xylose B3	5-Ureido-4-imidazole-carboxylate H1	<b>V</b>	Xanthine oxidase 1.1.3.22 G1
UDPglucose U5, U6	Ureidoglycolate I1	<i>cis</i> -Vaccenate E7	Xanthophylls E9
UDPglucose 4-epimerase 5.1.3.2 B4	Ureidoglycolate lyase 4.3.2.3 H1	L-Valine B10, K2	Xanthosine G1
UDPglucose dehydrogenase 1.1.1.22 B3	3-Ureidoisobutyrate L8	L-Valine-tRNA ligase 6.1.1.9 B10	Xanthosine 5'-phosphate G1
UDPglucose-hexose-1-phosphate uridylyltransferase 2.7.7.12 B4	3-Ureidopropionate 3.5.1.6 K8, L8	L-Valyl-tRNA B10	Xanthurenate J2
UDPglucuronate 4-epimerase 5.1.3.6 B3	3-Ureidopropionate K8	Vancomycin O3	Xeroderma pigmentosum Q8
UDPglucuronate decarboxylase 4.1.1.35 B3	Ureidosuccinase 3.5.1.7 G8	Vanillylmandelate H2	Xylan endo-1, 3 $\beta$ -xylosidase 3.2.1.32 C3
Uncoupling protein P9	Uridine J8	Very low density lipoprotein [VLDL] S3	Xylitol C3
Undecaprenyl N3	Uridine 5'-diphosphate [UDP] J8	Vinylreductase K6	L-Xylonate C2
	Uridine 5'-phosphate [UMP] J8	Violacein H2	D-Xylose C3
	Uridine 5'-triphosphate [UTP] J8	Virus O2	Xylose isomerase 5.3.1.5 C3, C6
	Uridine kinase 2.7.1.48 J7, J8	Virus integration Q8	Xylulokinase 2.7.1.17 C3
	Uridine nucleosidase 3.2.2.3 J8	Visual process V4	L-Xylulokinase 2.7.1.53 C4
	Uridine phosphorylase 2.4.2.3 J8	Vitamin A [retinol] D9	D-Xylulose C3
	d-Urobilin L6	Vitamin B <sub>12</sub> [cobalamin] I6	L-Xylulose C3
	i-Urobilin (IXa) L6	Vitamin C [ascorbate] B2	D-Xylulose 5-phosphate C5, U10
	d-Urobilinogen L6	Vitamin D <sub>2</sub> [ergocalciferol] F9	L-Xylulose 5-phosphate C3
	i-Urobilinogen L6	Vitamin D <sub>3</sub> [cholecalciferol] F9	D-Xylulose reductase 1.1.1.9 C3
	Urocanate F2		L-Xylulose reductase 1.1.1.10 C3
	Urocanate hydratase 4.2.1.49 F2	<b>Z</b>	Zoosterols H10
	Urocortisol K9		Zymosterol F10
	Urocortisone K9		