

Stable NAD/NADH derivatives

Description

The invention concerns stable nicotinamide adenine dinucleotide (NAD/NADH) and nicotinamide adenine dinucleotide phosphate (NADP/NADPH) derivatives, enzyme complexes of these derivatives and
5 their use in biochemical detection methods and reagent kits.

Measuring systems for biochemical analytics are important components of clinically relevant analytical methods. This primarily concerns the measurement of analytes e.g. metabolites or substrates which are determined directly or indirectly with the aid of an enzyme. The analytes are
10 converted with the aid of an enzyme-coenzyme complex and subsequently quantified. In this process the analyte to be determined is brought into contact with a suitable enzyme and a coenzyme where the enzyme is usually used in catalytic amounts. The coenzyme is changed e.g. oxidized or reduced by the enzymatic reaction. This process can be detected
15 electrochemically or photometrically either directly or by means of a mediator. A calibration provides a direct correlation between the measured value and the concentration of the analyte to be determined.

Coenzymes are organic molecules which are covalently or non-covalently bound to an enzyme and are changed by the conversion of the analyte.
20 Prominent examples of coenzymes are nicotinamide adenine dinucleotide (NAD) and nicotinamide adenine dinucleotide phosphate (NADP) from which NADH and NADPH respectively are formed by reduction.

Measuring systems known from the prior art are characterized by a limited shelf-life and by special requirements for the environment such as cooling or
25 dry storage in order to achieve this storage stability. Hence erroneous results

caused by incorrect, unnoticed, faulty storage can therefore occur for certain forms of application e.g. in the case of tests which are carried out by the end-users themselves such as glucose self-monitoring. In particular the exhaustion of desiccants due to opening the primary packaging for excessive periods can result in measuring errors which in some systems can be hardly recognized by the consumer.

A known measure that can be used to increase the stability of biochemical measuring systems is the use of stable enzymes e.g. the use of enzymes from thermophilic organisms. It is also possible to stabilize enzymes by chemical modification e.g. cross-linking or by mutagenesis. Furthermore, enzyme stabilizers such as trehalose, polyvinylpyrrolidone and serum albumin can also be added or the enzymes can be enclosed in polymer networks e.g. by photopolymerization.

It has also been attempted to improve the storage life of biochemical measuring systems by using stable mediators. Thus the specificity of tests is increased and interferences during the reaction are eliminated by using mediators having the lowest possible redox potential. However, the redox potentials of the enzyme/coenzyme complexes constitute a lower limit for the redox potential. If one falls below this limit, this reaction with the mediators is slowed down or even prevented.

Alternatively it is also possible to use biochemical measuring systems without mediators in which for example coenzymes such as the coenzyme NADH are directly detected. However, a disadvantage of such measuring systems is that coenzymes such as NAD and NADH are unstable.

NAD and NADH are base-labile molecules the degradation paths of which are described in the literature (N.J. Oppenheimer in The Pyridine Nucleotide Coenzymes Academic Press, New York, London 1982, J. Everese, B. Anderson, K. You, Editors, chapter 3, pages 56-65). Essentially ADP-ribose is

- formed during the degradation of NAD or NADP by cleavage of the glycosyl bonds between the ribose and the pyridine unit. The reduced forms NADH and NADPH are, however, acid labile: e.g. epimerization is a known degradation path. In both cases the instability of NAD/NADP and
- 5 NADH/NADPH is due to the lability of the glycosyl bond between the ribose and the pyridine unit. But even under conditions that are not drastic such as in aqueous solution, the coenzymes NAD and NADP are already hydrolysed solely by the ambient humidity. This instability can result in inaccuracies when measuring analytes.
- 10 A number of NAD/NADP derivatives are described for example in B.M. Anderson in the *Pyridine Nucleotide Coenzymes*, Academic Press New York, London 1982, J. Everese, B. Anderson, K. You, Editors, Chapter 4. However, most of these derivatives are not accepted well by enzymes. The only derivative which has therefore been previously used for diagnostic tests is
- 15 3-acetylpyridine adenine dinucleotide (acetyl NAD) which was first described in 1956 (N.O. Kaplan, *J. Biol. Chem.* (1956) 221, 823). This coenzyme is also not accepted well by enzymes and exhibits a change in the redox potential.
- The use of other NAD derivatives with a modified pyridine group is described
- 20 in WO 01/94370. However, modifications of the nicotinamide group usually have a direct effect on the catalytic reaction. In most cases this effect is negative.
- In another stabilization concept the ribose unit was modified in order to influence the stability of the glycosyl bond. This process does not directly
- 25 interfere with the catalytic reaction of the nicotinamide group. However, there may be an indirect effect as soon as the enzyme binds strongly and specifically to the ribose unit. In this connection Kaufmann et al. disclose a number of thioribose-NAD derivatives in WO 98/33936 and US 5,801,006 and WO 01/49247. However, a correlation between the modification of the

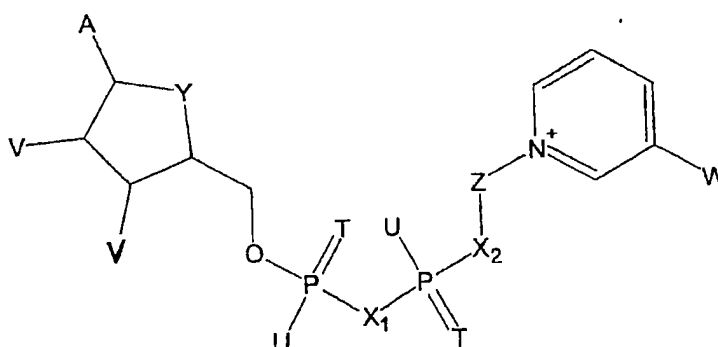
nicotinamide ribose unit and the activity of the derivatives in enzymatic reactions has previously not been demonstrated.

CarbaNAD, a derivative without a glycosyl bond was described for the first time in 1988 (J.T. Slama, Biochemistry 1989, 27, 183 and Biochemistry
5 1989, 28, 7866). In this derivative the ribose is substituted by a carbacyclic sugar unit. Although carbaNAD was described as a substrate for dehydrogenases, its activity has not yet been proven in clinical biochemical detection methods.

A similar approach was described later by G.M. Blackburn, Chem. Comm.,
10 1996, 2765 in order to synthesize carbaNAD with a methylene bisphosphonate linkage instead of the natural pyrophosphate. The methylene bisphosphonate is more stable towards phosphatases and was used as an inhibitor for ADP ribosyl cyclase. The aim was not to make it more resistant to hydrolysis (J.T. Slama, G.M. Blackburn).

15 Hence the object of the present invention is to provide stable bioanalytical measuring systems especially for determining glucose which avoid the sensitivity to hydrolysis of NAD/NADP and at the same time are active as coenzymes in enzyme reactions.

This object is achieved by a test element for determining an analyte
20 comprising (i) a coenzyme-dependent enzyme or a substrate for such an enzyme and (ii) a compound of the following general formula (I) as the coenzyme:



(I)

in which

- A = adenine or an analogue thereof,
- 5 T = in each case independently denotes O, S,
- U = in each case independently denotes OH, SH, BH_3^- , BCNH_2^- ,
- V = in each case independently denotes OH or a phosphate group,
- W = COOR , $\text{CON}(\text{R})_2$, COR , $\text{CNB}(\text{R})_2$ in which R in each case independently denotes H or $\text{C}_1\text{-C}_2\text{-alkyl}$,
- 10 $\text{X}_1, \text{X}_2 =$ in each case independently denote O, CH_2 , CHCH_3 , $\text{C}(\text{CH}_3)_2$, NH, NCH_3 ,
- Y = NH, S, O, CH_2 ,
- Z = a residue comprising a cyclic compound with 5 C atoms which optionally contains a heteroatom selected from O, S and N and optionally one or more substituents, and a residue CR_4 wherein
- 15 CR_4 is bound to the cyclic group and to X_2
- where $\text{R}_4 =$ in each case independently denotes H, F, Cl, CH_3 , provided that Z and the pyridine residue are not linked by a glycosidic bond, or a salt or optionally a reduced form thereof.
- 20 In a preferred embodiment $\text{W} = \text{CONH}_2$ or COCH_3 .

Preferred substituents on Z are selected from the group comprising OH, F, Cl and $\text{C}_1\text{-C}_2$ alkyl which are optionally fluorinated or chlorinated or/and OH-

substituted, O-C₁-C₂-alkyl.

In a preferred embodiment a first residue V is OH and a second residue V is a phosphate group. Optionally the one OH group and the one phosphate group can form a ring together with the carbon atoms to which they are
5 bound.

In a preferred embodiment a test element is provided to determine glucose which comprises a glucose dehydrogenase and a compound of the general formula (I) as mentioned above or a salt thereof.

Surprisingly the compounds according to the invention are stable towards
10 hydrolysis and are good substrates in enzymatic detection methods and can be used for biochemical diagnostics. This finding is in contrast to that of most of the previously known NAD/NADP derivatives since these derivatives are usually stable for only very short periods in enzymatic detection methods.

The advantages of the compounds according to the invention compared to
15 the prior art are:

- high stability,
- high enzymatic activity,
- simple and economic synthesis,
- they can be used in all previously known biochemical detection methods.

20 The disadvantages of the previously known biochemical detection methods can be largely avoided by the provision of stable NAD/NADP derivatives using the present invention preferably in combination with a stabilizing formulation such as for example by enclosing enzymes in polymer networks. Moreover, it is not necessary to use stabilizing additives. This is particularly
25 advantageous since the lower the number of reactive substances involved, the greater is the chance of obtaining a stable formulation for the analyte

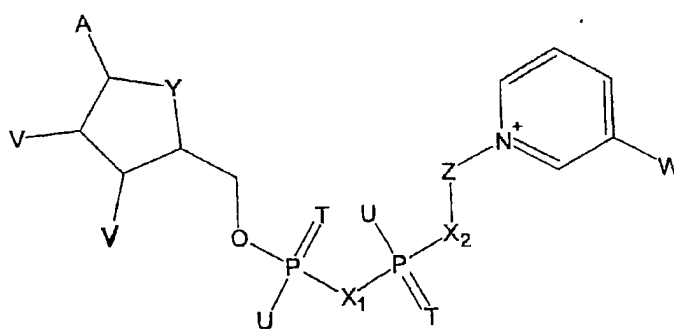
determination.

The present invention provides test elements comprising a number of stable NAD/NADP derivatives which have an adequate enzymatic activity for use as a coenzyme on the test element.

- 5 Stable NAD/NADP derivatives can be produced in generally known processes of synthesis. For this the amino group of a cyclic amino alcohol is converted into a pyridinium derivative by Zincke chemistry. The primary OH group is subsequently phosphorylated and coupled to an activated AMP derivative to form an NAD derivative. Alternatively the primary OH group can
10 also be firstly phosphorylated and then the amino group can be converted into a pyridine by means of the Zincke reaction.

Another synthetic route is to activate the primary alcohol to form a tosylate or iodide and subsequently alkylate ADP.

- Preferred embodiments of the test element according to the invention
15 comprise for example compounds having the following general formula (I'):

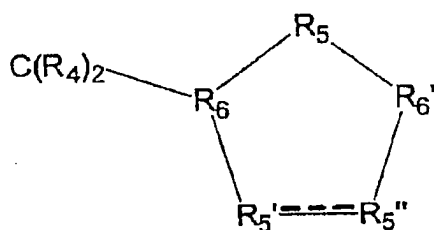


(I')

in which

- A = adenine or an analogue thereof,
20 T = in each case independently denotes O, S,

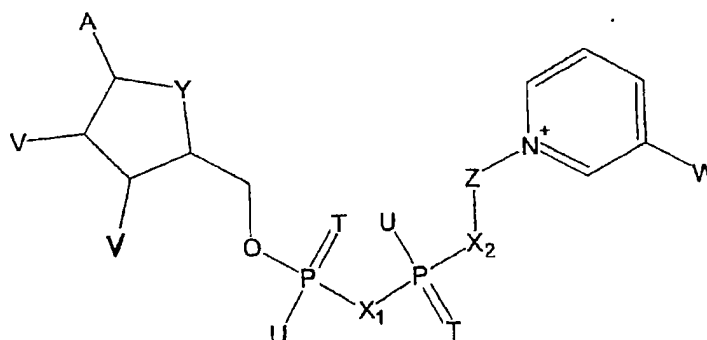
- U = in each case independently denotes OH, SH, BH_3^- , BCNH_2^- ,
V = in each case independently denotes OH or a phosphate group,
W = COOR, $\text{CON}(\text{R})_2$, COR, $\text{CSN}(\text{R})_2$ in which R in each case
independently denotes H or $\text{C}_1\text{-C}_2$ -alkyl,
5 X₁, X₂ = in each case independently denote O, CH₂, CHCH₃, $\text{C}(\text{CH}_3)_2$, NH,
NCH₃,
Y = NH, S, O, CH₂,
Z = a saturated or unsaturated carbocyclic or heterocyclic five-
membered ring, in particular a compound of the general formula
10 (II)



(II)

- in which a single or double bond can be present between R_{5'} and R_{5''},
R₄ = in each case independently denotes H, F, Cl, CH₃,
15 R₅ = CR₄₂,
if a single bond is present between R_{5'} and R_{5''}, then
R_{5'} = O, S, NH, NC₁-C₂-alkyl, CR₄₂, CHOH, CHOCH₃,
R_{5''} = CR₄₂, CHOH, CHOCH₃,
if a double bond is present between R_{5'} and R_{5''}, then R_{5'} = R_{5''} = CR₄,
20 R₆, R_{6'} = in each case independently denote CH, CCH₃
or a salt or optionally a reduced form thereof.

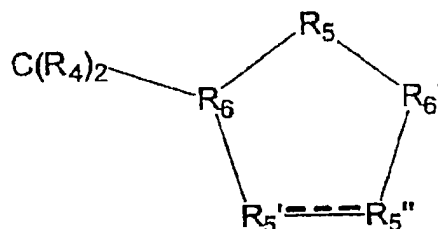
Compounds of the following general formula (I'') are another subject matter
of the invention:



(I'')

in which

- A = adenine or an analogue thereof,
- 5 T = in each case independently denotes O, S,
- U = in each case independently denotes OH, SH, BH_3^- , BCNH_2^- ,
- V = in each case independently denotes OH or a phosphate group,
- W = COOR , $\text{CON}(\text{R})_2$, COR , $\text{CSN}(\text{R})_2$ in which R in each case independently denotes H or C_1 - C_2 -alkyl,
- 10 $\text{X}_1, \text{X}_2 =$ in each case independently denote O, CH_2 , CHCH_3 , $\text{C}(\text{CH}_3)_2$, NH, NCH_3 ,
- Y = NH, S, O, CH_2 ,
- Z = a saturated or unsaturated carbocyclic or heterocyclic five-membered ring, in particular compounds of the general formula
- 15 (II)



(II)

- in which a single or double bond can be present between R_5' and R_5'' ,
- 20 $\text{R}_4 =$ in each case independently denotes H, F, Cl, CH_3 ,

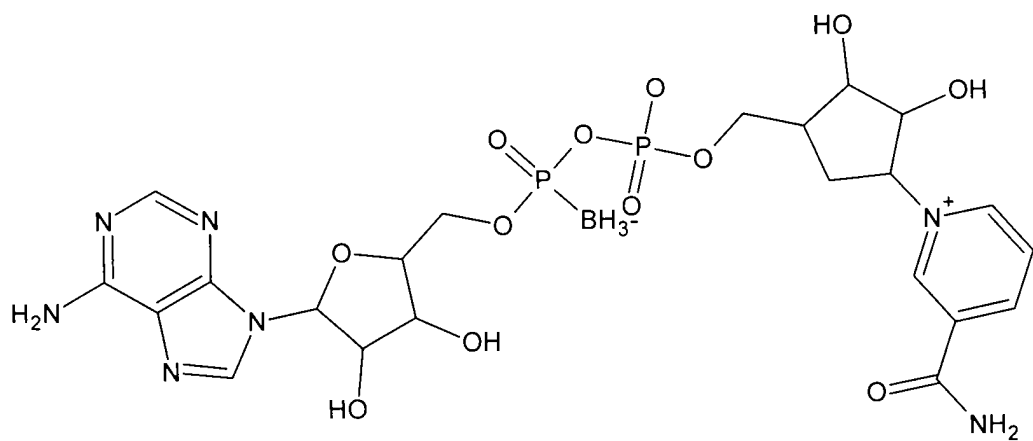
- R5 = CR₄,
 if a single bond is present between R5' and R5'', then
 R5' = O, S, NH, NC₁-C₂-alkyl, CR₄, CHOH, CHOCH₃,
 R5'' = CR₄, CHOH, CHOCH₃,
 5 if a double bond is present between R5' and R5'', then R5' = R5'' = CR₄,
 R6, R6' = in each case independently denote CH, CCH₃
 provided that if R5 = CH₂, T = O, U = in each case denotes OH, V = OH, W =
 CONH₂, X = O and Y = O then R5' and R5'' are not simultaneously CHOH,
 or a salt or optionally a reduced form thereof.
- 10 In a preferred embodiment the compounds according to the invention contain
 adenine analogues such as C₈-substituted and N₆-substituted adenine,
 deaza variants such as 7-deaza, aza variants such as 8-aza or combinations
 such as 7-deaza or 8-aza or carbocyclic analogues such as formycin where
 the 7-deaza variants can be substituted in the 7 position with halogen, C₁-C₆-
 15 alkynyl, C₁-C₆-alkenyl or C₁-C₆-alkyl.

In a further preferred embodiment the compounds contain adenosine
 analogues which contain for example 2-methoxydeoxyribose, 2'-fluorodeoxy-
 ribose, hexitol, altritol or polycyclic analogues such as bicyclic, LNA and
 tricyclic sugars instead of ribose.

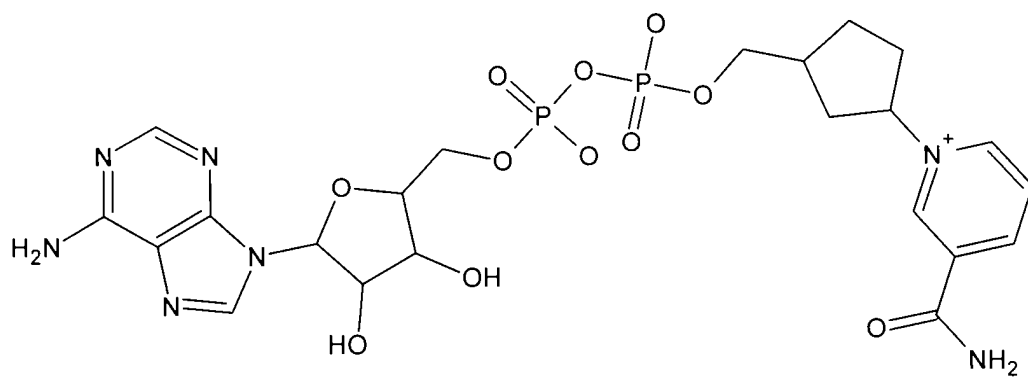
- 20 In particular (di)phosphate oxygens can also be isoelectronically substituted
 such as for example O⁻ by S⁻ or BH₃⁻, O by NH, NCH₃ or CH₂ and =O by =S.

In a preferred embodiment at least one residue U of the compound
 according to the invention is different from OH and particularly preferably at
 least one residue U = BH₃⁻.

- 25 Especially preferred embodiments are the derivatives borano carbaNAD,
 c-pentyl NAD, pyrrolyl NAD, furanyl NAD, carbaNADcyclophosphate,
 carbaNADP, pyrrolidiny NAD as well as test elements which contain them:

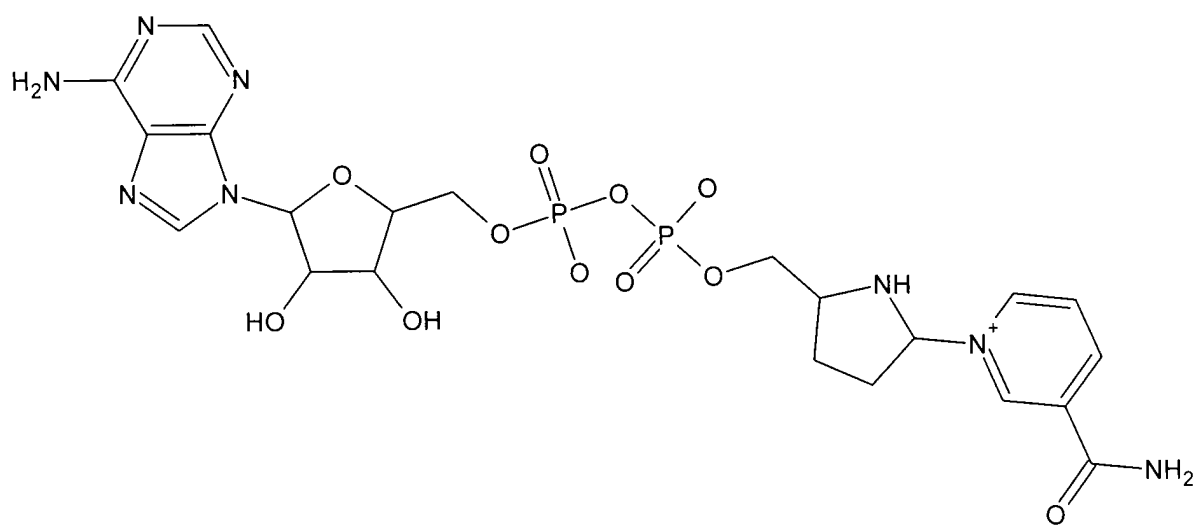


borano carbaNAD

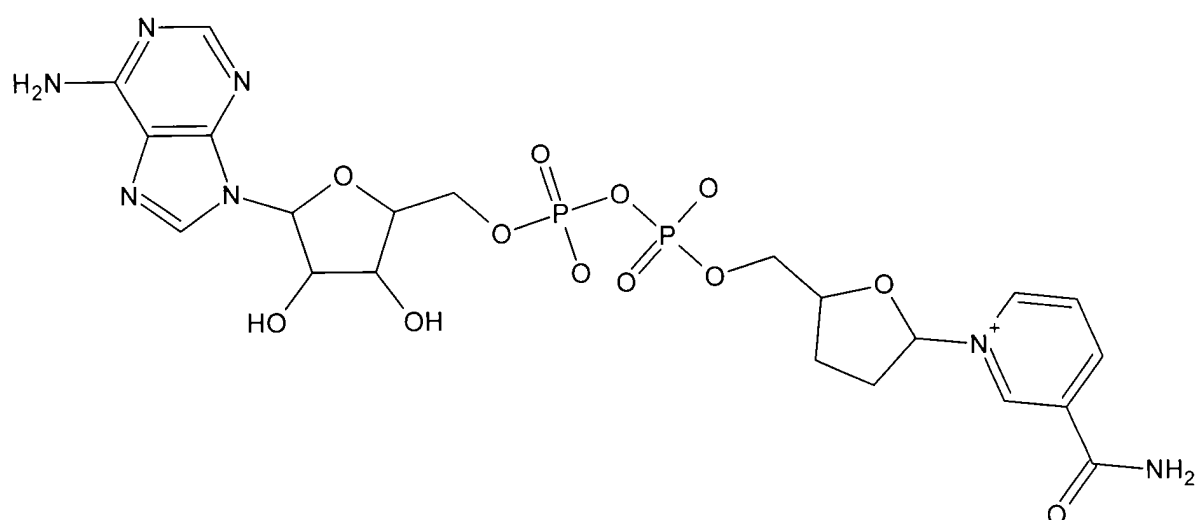


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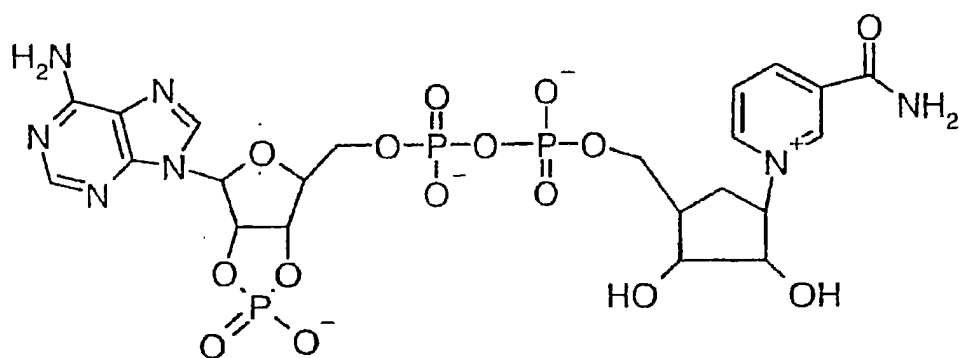
cyclopentyl NAD



10 pyrrolyl NAD

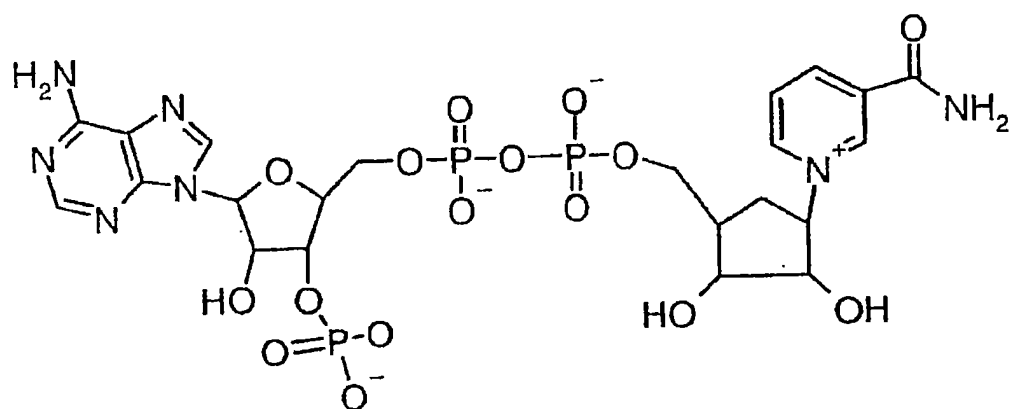


furanyl NAD

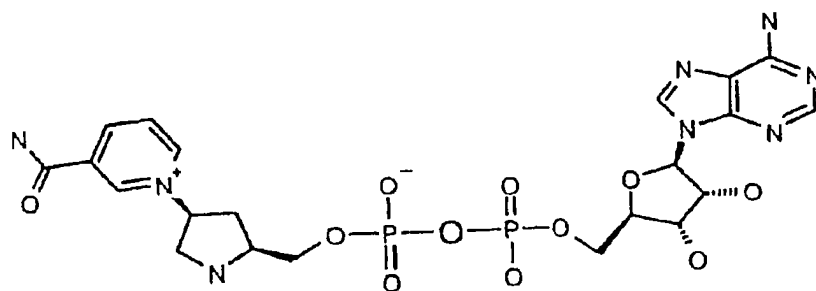


5

carbaNAD cyclophosphate



carbaNADP



pyrrolidinyI NAD

Biochemical tests for analytes, for example parameters in body fluids such
5 as blood, serum, plasma or urine or in samples of waste water or foods are
of major importance in diagnostics. In these tests the analyte to be
determined is brought into contact with a suitable enzyme and a coenzyme.

Hence, another subject matter of the present invention is an enzyme-
coenzyme complex consisting of a compound according to the invention in
10 combination with a suitable enzyme.

Any biological or chemical substances that can be detected by a redox
reaction can be determined as analytes e.g. substances which are
substrates of a coenzyme-dependent enzyme or the coenzyme-dependent
enzymes themselves. Preferred examples of analytes are glucose, lactic
15 acid, malic acid, glycerol, alcohol, cholesterol, triglycerides, ascorbic acid,
cysteine, glutathione, peptides, urea, ammonium, salicylate, pyruvate, 5'-
nucleotidase, creatine kinase (CK), lactate dehydrogenase (LDH), carbon
dioxide etc.

For the detection of enzyme substrates the test element preferably contains
20 an enzyme that is suitable for detecting the substrate, in addition to the
coenzyme. Suitable enzymes are for example dehydrogenases selected
from glucose dehydrogenase (E.C.1.1.1.47), lactate dehydrogenase

(E.C.1.1.1.27, 1.1.1.28), malate dehydrogenase (E.C.1.1.1.37), glycerol dehydrogenase (E.C.1.1.1.6), alcohol dehydrogenase (E.C.1.1.1.1), alpha-hydroxybutyrate dehydrogenase, sorbitol dehydrogenase or amino acid dehydrogenase e.g. L-amino acid dehydrogenase (E.C.1.4.1.5). Further
5 suitable enzymes are oxidases such as glucose oxidase (E.C.1.1.3.4) or cholesterol oxidase (E.C.1.1.3.6) or aminotransferases such as aspartate or alanine aminotransferase, 5'-nucleotidase or creatine kinase.

For the detection of enzymes the test element preferably contains an enzyme substrate suitable for detecting the enzyme, in addition to the
10 coenzyme.

Another subject matter of the present invention is the use of a compound according to the invention or of an enzyme-coenzyme complex according to the invention to detect an analyte in a sample by an enzymatic reaction. In this connection the detection of glucose with the aid of glucose
15 dehydrogenase (GlucDH) is particularly preferred.

The change in the coenzyme i.e. in the compound according to the invention by reaction with the analyte (if the analyte is an enzyme substrate) or by an analyte-catalysed reaction (if the analyte is an enzyme) can in principle be detected in any desired manner. Basically all methods for detecting
20 enzymatic reactions that are known from the prior art can be used. However, the change in the coenzyme is preferably detected by optical methods. Optical detection methods for example include the measurement of absorption, fluorescence, circular dichroism (CD), optical rotary dispersion (ORD), refractometry etc. The change in the coenzyme is particularly
25 preferably detected by measuring the fluorescence. Fluorescence measurement is highly sensitive and enables the detection even of low concentrations of the analyte in miniaturized systems.

A liquid test can be used to detect an analyte in which the reagent is for

example present in the form of a solution or suspension in an aqueous or non-aqueous liquid or it is present as a powder or lyophilisate. It is, however, also possible to use a dry test, in which case the reagent is applied to a carrier, a test strip. The carrier can for example be a test strip comprising an absorbent or/and swellable material that is wetted by the sample liquid to be examined.

A gel matrix in which an enzyme-coenzyme complex is incorporated can, however, also be used as a detection reagent (cf. DE 102 218 45 A1).

In this case the enzyme can either be polymerized into the matrix together with the compound according to the invention or, after the polymerization, the matrix can be contacted with a solution of the coenzyme in the presence of the enzyme to form the corresponding enzyme-coenzyme complex.

Another subject matter of the present invention concerns a reagent kit and its use to detect analytes. The reagent kit can contain a compound according to the invention, a suitable enzyme and a suitable reaction buffer. Suitable enzymes have already been described. The reagent kit according to the invention can be used in a wide variety of ways and can be used to determined analytes such as glucose, lactic acid, malic acid, glycerol, alcohol, cholesterol, triglycerides, ascorbic acid, cysteine, glutathione, peptides, urea, ammonium, salicylate, pyruvate, 5'-nucleotidase, creatine kinase (CK), lactate dehydrogenase (LDH) and carbon dioxide etc. A reagent kit is preferred which contains a compound according to the invention and glucose dehydrogenase (E.C.1.1.1.47) to detect glucose in blood.

The reagent kit according to the invention can be used to detect an analyte in a dry or liquid test.

Another subject matter of the present invention concerns a test strip for the

fluorometric or photometric detection of an analyte. Such a test strip contains a compound as stated above as a coenzyme and a suitable enzyme or an enzyme substrate immobilized on an absorbent or/and swellable material. Suitable materials can for example be selected from cellulose, plastics etc.

- 5 Another subject matter of the present invention comprises a method for detecting an analyte comprising the steps:
- (a) contacting a sample with a test element or reagent kit according to the invention comprising a coenzyme and
 - (b) detecting the analyte e.g. on the basis of the change in the coenzyme.
- 10 Another advantage of the invention is that the fluorescence emission of the coenzymes exhibits a bathochromic shift and hence there is less interference with the fluorescence emission of other materials of the test element or/and of the sample.
- 15 All preferred embodiments of a subject matter of the present invention that are shown are also intended to apply to other subject matters of the invention such as e.g. preferred embodiments of the compounds according to the invention.

The invention is to be elucidated in more detail by the following figures and examples.

Figure legends

Figure 1

Diagram of the process for synthesizing carbaNAD (cNAD).

Figure 2

5 Graph of the results of stressing NAD at 8°C and 37°C.

Figure 3

Graph of the results of stressing carbaNAD at 8°C and 37°C.

Figure 4

10 Diagram of the process for synthesizing borano NAD by alkylating ADP,
where $Y = BH_3$, only the beta phosphate of ADP was alkylated.

Figure 5

Diagram of the process for synthesizing pyrrolidinyI NAD (pNAD). Compound numbers and yields of the respective reaction steps are stated next to the structural formulae.

15 Figure 6A/6B

Absorption spectra of NAD and pNAD (figure 6A) and NADH and pNADH (figure 6B).

Figure 7

20 Fluorescence spectra of NADH and pNADH as a GlucDH complex (emission spectra).

Figure 8

Fluorescence spectra of NADH and pNADH as a GlucDH complex (excitation spectra).

Figure 9

5 Comparison of the stability of NAD and pNAD.

Figure 10A /10B/10C

Absorption spectra of NAD and cNAD (figure 10A) and of NADH and cNADH (figures 10B and 10C).

Figure 11

10 Fluorescence spectra of NADH and cNADH as a GlucDH complex.

Examples

Experimental preparation of stable NAD/NADH derivatives

The preparation of stable NAD/NADH derivatives is shown on the basis of carbaNAD (compound 9, figure 1) and pyrrolidine NAD (compound 18, figure 15 5) as examples. Additional derivatives can be prepared using appropriate processes of synthesis. The corresponding amino alcohols used as starting reagents are known in the literature:

2-amino-1,4-anhydro-2,3-dideoxy-L-threo-pentitol: Huryn, Donna M.;

Sluboski, Barbara C.; Tam, Steve Y.; Todaro, Louis J.; Weigele, Manfred

20 Tetrahedron Letters (1989), 30(46), 6259-62.

3-amino-, (1R,3S)-cyclopentanemethanol, Beres, J.; Sagi, G.; Tomoskozi, I.; Gruber, L.; Gulacsi, E.; Otvos, L.; Tetrahedron Letters (1988), 29(22), 2681-4.

A) Preparation of carbaNAD

I. 1R-(-)-exo-*cis*-5,6-dihydroxy-2-azabicyclo[2.2.1]heptan-3-one (1)

A solution of 16.4 g (147 mmol) 1R-(-)-2-azabicyclo[2.2.1]hept-5-en-3-one in 400 ml acetone is added to a solution of 22.5 g (167 mmol) N-methyl-morpholine-N-oxide in 80 ml deionised water in a 1 l round-bottomed flask.
5 15 ml (1.2 mmol) of a 2.5 % solution of osium tetroxide in *tert*-butanol is added within 15 min while cooling on ice. The mixture is subsequently stirred overnight at room temperature.

The solvent is removed by distillation in a rotary evaporator. It is stirred with
10 100 ml and again distilled off in a rotary evaporator. Afterwards it is dissolved in 600 ml deionised water and 35 g activated carbon is added. The mixture is stirred vigorously for 1 h and then filtered over a Seitz K 250 deep-bed filter. Water is removed from the filtrate by distillation in a rotary evaporator. The product is used without further purification.

15 TLC (Merck silica gel 60 F-254): ethyl acetate / methanol / glacial acetic acid 7:2:1 R_f 0.75 (starting material), 0.53 (1). Staining with TDM / development in a chlorine chamber.

* TDM reagent: Solution 1: 10 g N,N,N',N'-tetramethyl-4,4'-diamino-diphenyl methane in 40 ml glacial acetic acid and 200 ml deionised water. Solution 2:
20 20 g potassium chloride in 400 ml deionised water. Solution 3: Dissolve 0.3 g ninhydrin in 10 ml glacial acetic acid and add 90 ml deionised water.
Finished reagent: A mixture of solution 1 and 2 and addition of 6 ml of solution 3.

**II 1R-(-)-exo-cis-5,6-dimethylmethylenedioxy-2-azabicyclo[2.2.1]
heptan-3-one (2)**

The crude product 1 is boiled under reflux for 1 h in 200 ml absolute ethanol. After adding 400 ml (3.26 mol) dimethoxypropane and 250 mg (2.2 mmol)
5 pyridine hydrochloride, the mixture is boiled under reflux for a further 15 min. After adding 10 ml saturated sodium hydrogen carbonate solution, the solution is evaporated to dryness under a vacuum in a rotary evaporator. 500 ml Chloroform, 150 ml saturated sodium chloride solution and 75 ml
10 saturated sodium hydrogen carbonate solution are added to the residue and it is transferred to a separating funnel. After extraction by shaking it is allowed to stand overnight during which phase separation takes place.

The organic phase is separated and the aqueous phase is extracted for a further two times with 200 ml chloroform in each case. The combined organic
phases are dried over magnesium sulfate. After removing the desiccant by
15 filtration, the solvent is removed by distillation under reduced pressure on a rotary evaporator. The crude product (24.9 g = 92 %) is used without further purification.

TLC (Merck silica gel 60 F-254): ethyl acetate / methanol / glacial acetic acid 7:2:1 R_f 0.84. Staining with TDM / development in a chlorine chamber).

20 III. 1R-(-)-4-N-*tert*-butyloxycarbonyl-exo-cis-5,6-dimethylmethylenedioxy-2-2-azobicyclo[2.2.1]heptan-3-one (3)

41.5 g (190 mol) di-*tert*-butyl dicarbonate and 0.83 g (6.8 mmol) 4-dimethyl-aminopyridine are added under argon to a solution of 24.9 g (135.7 mmol)
crude product 2 in 450 ml absolute chloroform. The mixture is boiled under
25 reflux while stirring until the gas evolution ceases. The mixture is filtered over a column that is filled with 40 g silica gel 60 and equilibrated with chloroform.

It is washed with 100 ml chloroform. The solvent is removed from the filtrate by distillation under reduced pressure on a rotary evaporator. The crude product is dried for 60 min at 10 mbar and 40°C. It is used without further purification.

- 5 TLC (Merck silica gel 60 F-254): ethyl acetate / hexane 3:2 R_f 0.85. Staining with TDM / development in a chlorine chamber).

IV. (-)-(1R,2R,3S,4R)-4-(N-*tert*-butyloxycarbonyl)amino-2,3-dimethyl-methylenedioxy-1-(hydroxymethyl)cyclopentane (4)

- The crude product 3 is dissolved at room temperature in 400 ml
10 tetrahydrofuran while stirring and 80 ml deionised water is added. After cooling to 4°C 5.3 g sodium borohydride is added all at once and stirred overnight during which the mixture is allowed to slowly heat up to room temperature. 100 ml ethanol is added and it is stirred for 6 h at room temperature. The solvents are removed by distillation under reduced
15 pressure on a rotary evaporator. 300 ml saturated sodium chloride solution and 650 ml ethyl acetate are added and it is transferred to a separating funnel. The organic phase is separated and the aqueous phase is again washed with 350 ml ethyl acetate. The combined organic phases are dried over magnesium sulfate. After removing the desiccant by filtration, the
20 solvent is removed by distillation under reduced pressure on a rotary evaporator. The crude product (42.4 g) is purified by means of column chromatography and silica gel 60 (column h = 93 cm, d = 10 cm) eluant THF / hexane 1:3, then THF / hexane 2:3), flow rate 3 l/h. 40 ml fractions are collected. The fractions are monitored by TLC (Merck silica gel 60 F-254:
25 ethyl acetate / hexane 3:2 R_f 0.45. Staining with TDM / development in a chlorine chamber). The solvent is removed from the combined product fractions by distillation in a vacuum on a rotary evaporator, yield: 24.9 g.

V. (-)-(1R,2R,3S,4R)-4-amino-2,3-dihydroxy-1-(hydroxymethyl)cyclopentane (5)

8 ml Deionised water and then 80 ml trifluoroacetic acid are added to 11.09 (38.6 mmol) 4. It is stirred vigorously for 6 h at room temperature during
5 which a clear pale yellow solution forms. 200 ml deionised water is added and it is evaporated under a vacuum on a rotary evaporator. 200 ml deionised water is again added and it is again evaporated under a vacuum on a rotary evaporator. The crude product is dissolved in 100 ml deionised water in an ultrasonic bath and filtered. The filtrate is applied to a Dowex 1X8
10 (100-200 mesh, OH form) ion exchanger column (15 x 4.9 cm) and eluted with water during which the product elutes after about 150 ml in a volume of 300 ml (pH 10.4). The fractions are monitored by TLC (Merck silica gel 60 F-254: butanol / glacial acetic acid / water 5:2:3 R_f 0.42. Staining with TDM / development in a chlorine chamber). The solvent is removed from the
15 combined product fractions by distillation in a vacuum on a rotary evaporator, yield: 5.2 g colourless oil.

VI. Zincke salt of the nicotinamide (6)

58.6 g Dinitrochlorobenzene is melted under nitrogen and then 29.32 g nicotinamide is added to the melt. It is heated for 2.5 h at 110°C. 500 ml of a
20 3:2 (v/v) ethanol / water mixture is added through a reflux cooler and it is boiled under reflux until a solution is formed. After stirring overnight at room temperature, 150 ml 50 % ethanol / water and 100 ml water are added, it is transferred to a separating funnel and washed three times with 500 ml chloroform each time. 300 ml and 50 g active carbon are added to the
25 separated aqueous phase which is stirred for 1 h at room temperature and then filtered over a Seitz K 700 deep-bed filter. The filtrate is concentrated in a vacuum to about 100 ml on a rotary evaporator during which the bath temperature must not exceed 20°C. It is diluted with 300 ml water and 70 g

sodium tetrafluoroborate is added at room temperature while stirring. The precipitate is recrystallized from methanol /water. The crystallisate is removed by filtration, washed with a small amount of acetone and then with diethyl ether and dried for 24 h in a high vacuum at 40°C (yield 21.1 g 23 %).

- 5 The fractions are monitored by TLC (Merck silica gel 60 F-254: butanol / glacial acetic acid /water 5:2:3 R_f = 0.56).

VII. (-)-(1R,2R,3S,4R)-4-(3-carboxamidopyridin-1-yl)-2,3-dihydroxy-1-(hydroxymethyl)cyclopentane (6) = carba nicotinamide mononucleoside = carbaNMN

- 10 A solution of 4.5 g (31 mmol) cyclopentylamine 5 in 110 ml absolute methanol is added dropwise within 90 minutes to a solution of 15.3 g (40.7 mmol) of the Zincke salt 6 in 110 ml absolute methanol while stirring at room temperature. 1 ml diisopropylethylamine is added and it is then stirred for two days at room temperature. 500 ml water is added, it is transferred to
- 15 a separating funnel and washed twice with 200 ml methylene chloride each time. The water is removed from the separated aqueous phase by distillation under a vacuum on a rotary evaporator. The residue is taken up in 100 ml water and purified by column chromatography on Sephadex C25 (Na⁺ form): column 70 x 7.5 cm elution of buffer A (deionised water) to buffer B 0.35 M
- 20 NaCl in water, flow rate 200 ml/h. 15 ml fractions are collected and monitored by TLC (Merck silica gel 60 F-254: butanol / glacial acetic acid / water 5:2:3 R_f 0.22).

- The solvent is removed from the combined product fractions by distillation in a vacuum on a rotary evaporator. The salt-containing residue is boiled out
- 25 with 500 ml hot ethanol. It is hot-filtered and allowed to stand for 12 h at room temperature. The precipitate is removed by filtration and the solvent is removed from the filtrate by distillation under a vacuum on a rotary evaporator. Yield 7 g.

VIII. (-)-(1R,2R,3S,4R)-4-(3-carboxamidopyridin-1-yl)-2,3-dihydroxy-1-phosphatoylmethyl)cyclopentane (6) = carbaNMN monophosphate

A mixture of 20 ml phosphoroxo chloride and 50 ml trimethyl phosphate is added at 0°C to a suspension of 7 g (27.7 mmol) carbaNMN in 80 ml anhydrous trimethyl phosphate. It is stirred for 2 h at 0°C and then for 2 h at room temperature. 300 ml water is added while cooling on ice and the mixture is evaporated to 10 ml under a vacuum on a rotary evaporator. It is taken up in 100 ml water, filtered and purified by means of column chromatography on Sephadex C25 (NEt₃H⁺ form): column 66 x 9 cm, elution of buffer A (deionised water) to buffer B 0.60 M ammonium acetate, flow rate 200 ml/h. 15 ml fractions are collected and monitored by TLC (Merck silica gel 60 F-254 plates: isobutyric acid / ammonia / water 66:1:33, R_f 0.25). The solvent is removed from the combined product fractions by distillation in a vacuum on a rotary evaporator. The residue is dissolved in 100 ml water and lyophilized. This procedure is repeated three times. Yield 4.0 g.

IX. carbaNAD (9)

A solution of 1.25 g (30 mmol) AMP morpholidate in 40 ml absolute DMF is added dropwise within 1 h at room temperature to a mixture of a solution of 3.31 g (10 mmol) carbaNMN monophosphate in 40 ml absolute DMF and 78 ml (39 mmol) 3.5 % tetrazole in absolute acetonitrile. The mixture is stirred for 2 days at room temperature.

The pH is adjusted to 6.5 using an aqueous 10 % KHCO₃ solution while cooling on dry ice / acetone. It is diluted with 500 ml water and carefully concentrated to dryness in a vacuum on a rotary evaporator. The residue is dissolved in 150 ml deionised water and purified by column chromatography on Sephadex QAE 25 (NEt₃H⁺ form): column 65 x 4.5 cm, elution of buffer A (deionised water) to buffer B 1 M triethylammonium carbonate, flow rate 200

ml/h: 15 ml fractions are collected and monitored by TLC (Merck silica gel 60 F-254 plates: isobutyric acid / ammonia / water 66:1:33, R_f 0.47).

The solvent is removed by distillation from the combined product fractions by distillation in a vacuum on a rotary evaporator. The residue is dissolved in
5 100 ml water and lyophilized. This procedure is repeated three times. Yield 1.1 g.

Examination of the stability of carbaNAD

A 10 mM solution of carbaNAD or NAD is stressed at pH 8 in 0.1 M potassium
phosphate buffer. The content is determined by means of HPLC
10 chromatography after 0.25, 75 and 175 h.

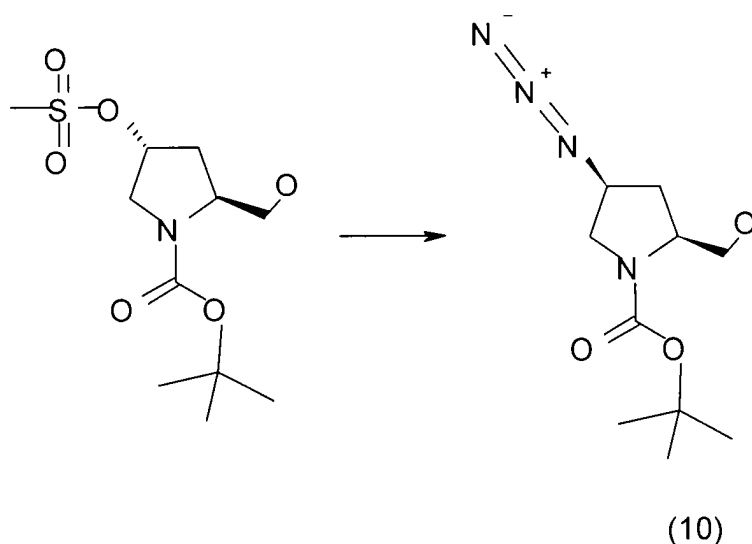
Buffer A: 100 mM KHPO_4 + 10 mM tetrabutylammonium hydrogen sulfate,
pH 6.9
buffer B: buffer A + acetonitrile 1:1
flow rate 1.0 ml/min detection: 254 nm
15 RP18 column L 125 diameter 4.6 mm
gradient: in 40 min to 35 % buffer B, hold for 2 min and then change to 0 %
buffer A within 3 min.

The HPLC area percentages after stressing for the various times are shown
in figures 2 and 3.

20 The occurrence of decomposition products (nicotinamide, ADP-ribose, AMP,
ADP and the unknown decomposition products for NAD and the unknown
decomposition products Y1 and Y2 for cNAD) show that cNAD is very stable
compared to NAD.

B) Preparation of pyrrolidiny-NAD

I. Synthesis of pNAD 1st stage (compound 10)



5

Trans-N-t-BOC-O-mesyl-4-hydroxyl-L-prolinol (35.4 g, 120 mmol) was dissolved in 500 ml DMF and sodium azide (15.6 g, 240 mmol) dissolved in 75 ml water was added and heated for 5 h to 70°C. It was subsequently stirred further overnight at room temperature, the mixture was poured into 1000 ml saturated sodium chloride solution and extracted with ethyl acetate. The ethyl acetate was dried with Na₂SO₄ and subsequently evaporated.

10

32.8 g (> 100 %) residue was formed (theoretical value: 29 g).

15

The crude product was directly processed further after TLC and MS monitoring. A thin layer chromatography on a KG 60 F-254 plate (mobile solvent: ethyl acetate /sprayed with ninhydrin) was carried out for the monitoring:

trans-N-t-BOC-O-mesyl-4-hydroxy-L-prolinol R_f: 0.49

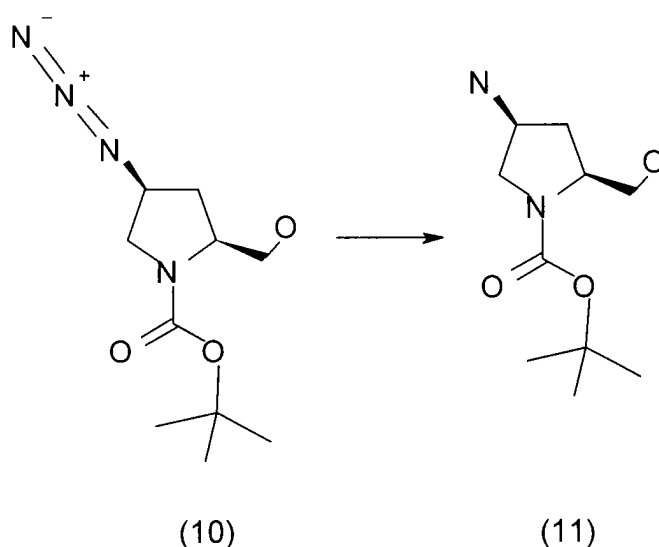
product R_f : 0.78

MS ESI ES+ 242

The identity of the product was also confirmed by NMR analysis.

*trans-N-t-BOC-O-mesyl-4-hydroxyl-L-prolinol is commercially available from
5 Sanochemia Pharmazeutika AG, Cat. No. P-719.

II. Synthesis of pNAD 2nd stage (compound 11)



10 Compound 10 (120 mmol) was mixed in 500 ml methanol with 2.0 g Pd-carbon (10 %) and hydrogenated for 12 h at 30 mbar. In this process the reaction flask was flushed several times with H_2 , the catalyst was removed by suction filtration and it was concentrated.

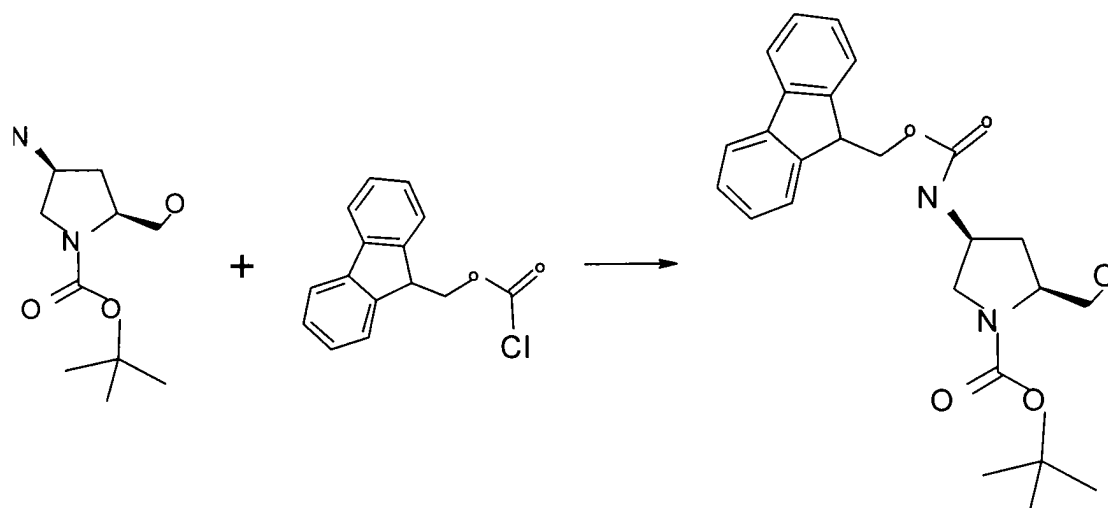
A colourless oil was formed (the oil should be immediately processed further due to its high air-sensitivity).

15 MS ESI ES+ 217 present

TLC (isohexane / ethyl acetate 1/1 / KG 254 F/ninhydrin): product remains at the start.

The identity of the product was also confirmed by NMR analysis.

III. Synthesis of pNAD 3rd stage (compound 12)



5 (11)

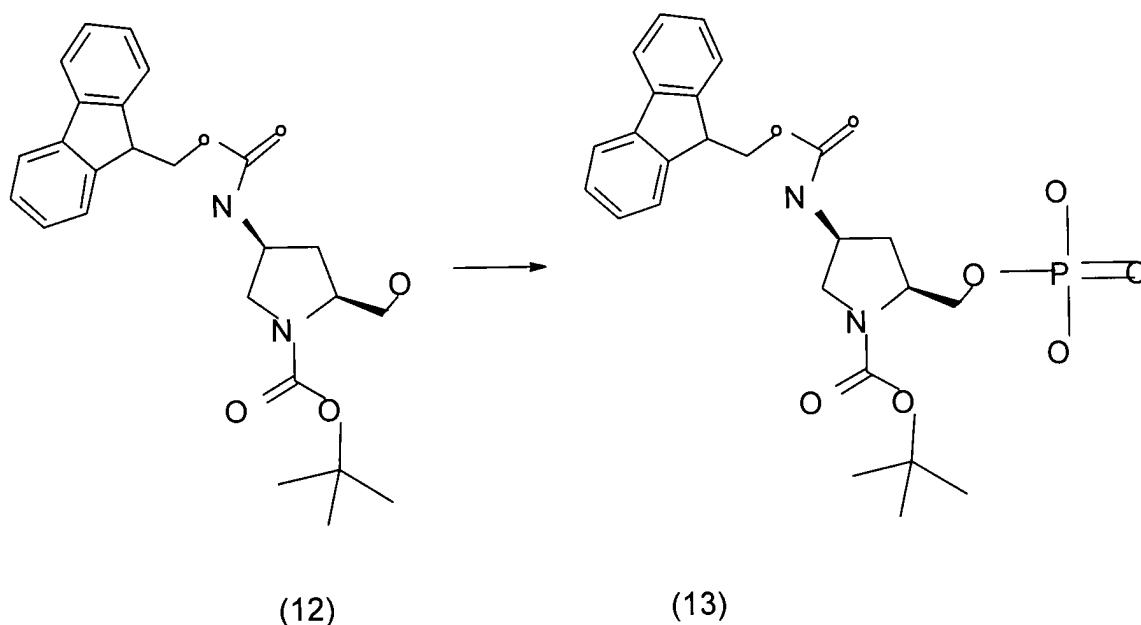
(12)

120 mmol of compound 11 (MW: 216.28) was mixed in 500 ml dioxane containing NaHCO_3 (11.0 g, 130 mmol) and Fmoc chloride (33.8 g, 130 mmol) and stirred overnight at room temperature. The resulting salts were removed by filtration, the solution was evaporated and the residue was
10 purified over a silica gel column (isohexane and isohexane / EE 8/2 – 1/1). The main fraction yielded 39.0 g = 74.1 % * (theoretical value = 52.6 g).
TLC (KG 60 F254 mobile solvent isohexane / ethyl acetate 2:1): R_f 0.13
MS ESI ES+ 439 / + 339

The identity of the product was also confirmed by NMR analysis.

15 * Yield refers to the educt of the 1st stage.

IV. Synthesis of pNAD 4th stage (compound 13)



Compound 12 from stage 3 (7.08 g, 16.1 mmol) was dissolved in 80 ml trimethyl phosphate and subsequently cooled to 0°C in an ice bath. POCl₃ mixed with trimethyl phosphate (13 ml freshly distilled POCl₃ in 13 ml trimethyl phosphate) was added to a dropping funnel and added in portions within 20 min under argon. The temperature increased in an exothermal reaction to up to 5°C. Subsequently 2.6 ml pyridine was added and it was stirred for a further 40 min at 0°C and under argon.

The reaction solution was carefully added dropwise to 800 ml ice-cooled 1 M triethylammonium hydrogen carbonate solution (pH = 8). After the addition was completed, it was stirred for a further 1 h. The slightly turbid solution was subsequently added (rapidly) dropwise to 1 l saturated NaCl solution. It was stirred further overnight to improve the crystallization. The precipitate was removed by filtration. The residue was desalted over a Diaion column. For this purpose 500 g Diaion was added to isopropanol / water 1/1 and allowed to swell overnight. Diaion was filled into the column and rinsed with water. A

slurry of the residue was formed in 100 ml water pH 3.5 (ethyl acetate) which was subsequently applied to a column and rinsed with water (pH 3.5) until it was free from sodium chloride. The substance was then eluted from the column with 25 % isopropanol (pH 3.5). The solution was evaporated in a high vacuum at room temperature.

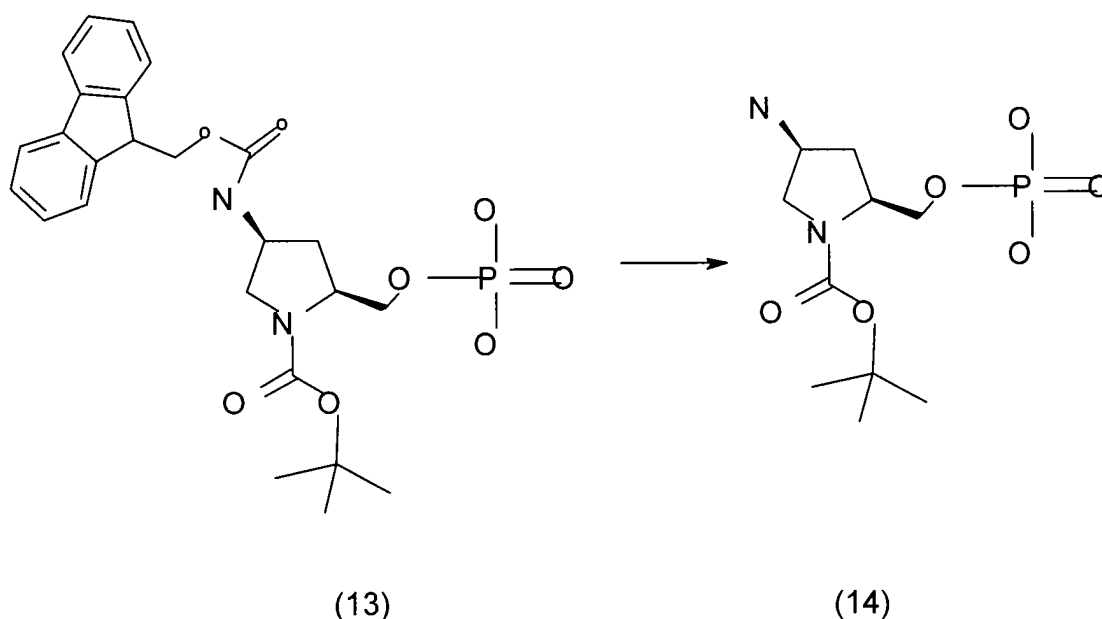
Residue = 2.6 g = 31.3 %

TLC RP8 F254 / MeOH / water 9/1

MS ESI ES+ 517.13

The identity of the product was also confirmed by NMR analysis.

V. Synthesis of pNAD 5th stage (compound 14)



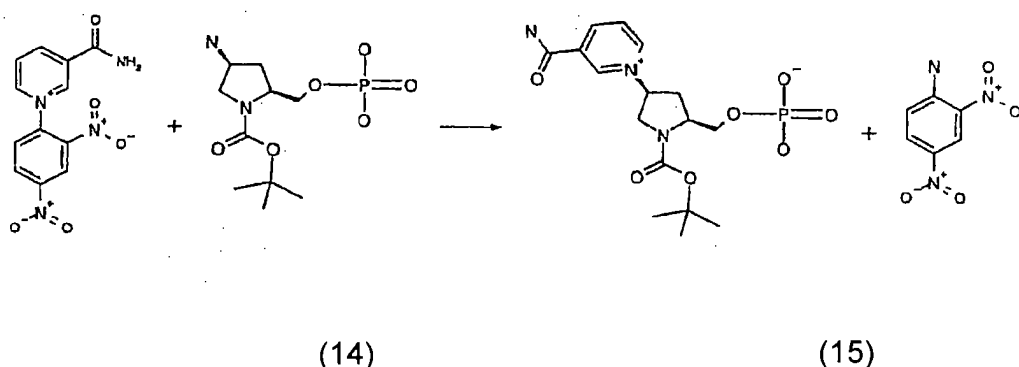
A mixture of compound 13 from stage 4 (4.10 g, 7.9 mmol) in 250 ml methanol and 83 ml 25 % ammonia was stirred overnight at room temperature and evaporated in a vacuum at room temperature. The residue was taken up in 200 ml water and stirred out three times with 100 ml ethyl acetate. Insoluble components were removed by filtration; the clear water phase was separated and again evaporated at room temperature.

Residue = 2.56 g = 100 %

MS ESI ES – 295

In order to remove the NH_3 cations, the residue was dissolved 2 x in Hünig's base and again evaporated each time in a high vacuum.

5 **VI. Synthesis of pNAD 6th stage (compound 15)**



The Zincke salt (2.66 g, 8.99 mmol) was prepared dissolved in 50 ml methanol and compound 14 from stage 5 (2.56 g, 8.31 mmol) dissolved in 50 ml methanol was added dropwise while stirring. The mixture colours red and slowly dissolves. It was stirred further overnight at room temperature and the precipitate was removed by filtration. The filtrate was evaporated in a vacuum, taken up in 100 ml water and extracted three times with ethyl acetate.

The ethyl acetate phase contains the by-product dinitroaniline, the water phase contains the product and the remaining Zincke salt. The water phase was evaporated in a vacuum at room temperature and 10 ml water was added to the residue that was obtained, which was stirred for 10 min on a magnetic stirrer and insoluble components were removed by filtration. The product remained dissolved. This solution was applied to a Diaion HP20 column (1000 ml) that had been rinsed with water and was rinsed two times with 1000 ml water. Subsequently it was rinsed with water / 5 % isopropanol

and positive fractions (detected by TLC RP8 MeOH / W 9/1) were evaporated at room temperature. The residue was triturated with isopropanol and suction filtered with the aid of diethyl ether.

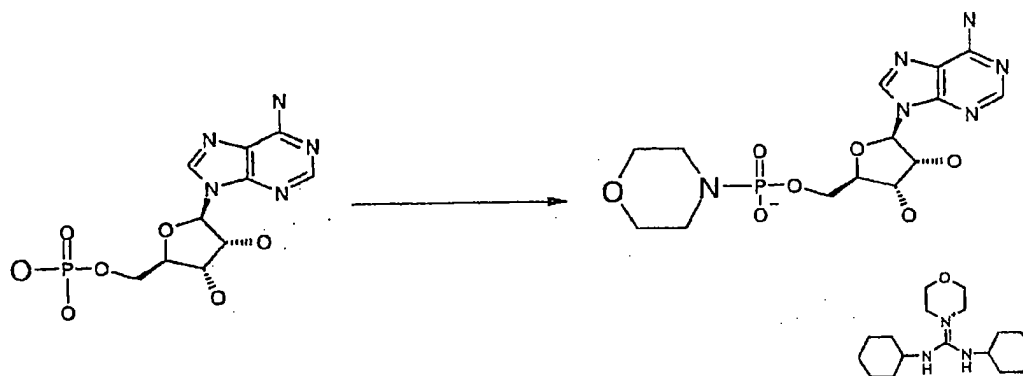
Residue = 1.60 g = 47.9 %

5 TLC RP8 254 MeOH / W 9/1

MS ES – 400.1 / ES + 402.0 also exhibits the double mass

The identity of the product was also confirmed by NMR analysis.

VIIa. Synthesis of pNAD stage 7a (compound 16)



10

(16)

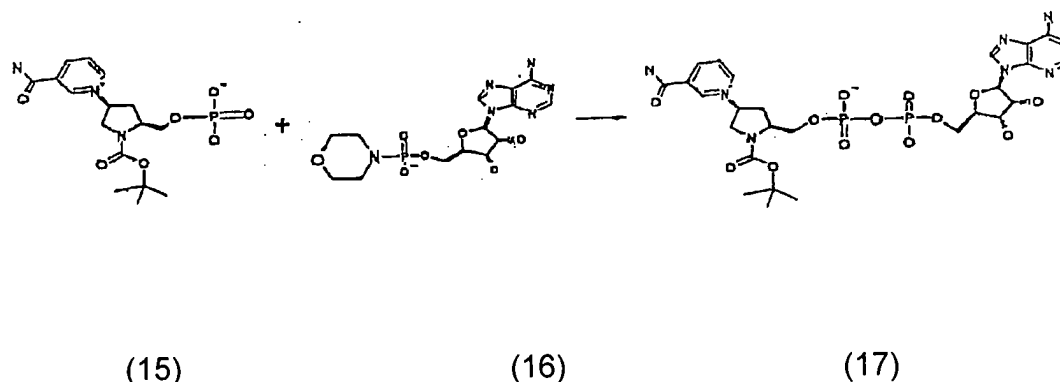
A mixture of AMP acid (adenosine monophosphate-free acid) (10 g, 27.5 mmol) in 60 ml methanol (dried with sodium) and 5.3 ml (60 mmol) morpholine (freshly distilled) was stirred until a clear solution was formed. Subsequently 17 g (82.5 mmol) N,N'-dicyclohexyl carbodiimide (DCC) was added and stirred overnight at room temperature while excluding moisture. The precipitate (DCH) that was formed was suction filtered and the filtrate was rotary evaporated at 30°C. Subsequently it was stirred out with 150 ml H₂O / 150 ml diethyl ether and again filtered. After phase separation the aqueous phase was again extracted twice with 75 ml diethyl ether each time. The aqueous phase was subsequently rotary evaporated at room temperature. The residue was dissolved a further two times in pyridine and

15

20

each time again rotary evaporated in a high vacuum.

VII. Synthesis of pNAD 7th stage (compound 17)



- 5 A mixture of AMP morpholidate (compound 16 from stage 7a) (2.53 g, 3.61 mmol), compound 15 from stage 6 (1.60 g, 3.98 mmol), MnCl_2 solution in formamide 0.2 M* (27.1 ml, 5.42 mmol) and anhydrous MgSO_4 (0.87 g, 7.95 mmol) were stirred overnight at room temperature and after this time were largely converted as determined by TLC (RP8 MeOH / W 9/1). The
10 reaction mixture was precipitated with acetonitrile and suction filtered.

Residue = 5.3 g (theoretical yield 2.64 g)**

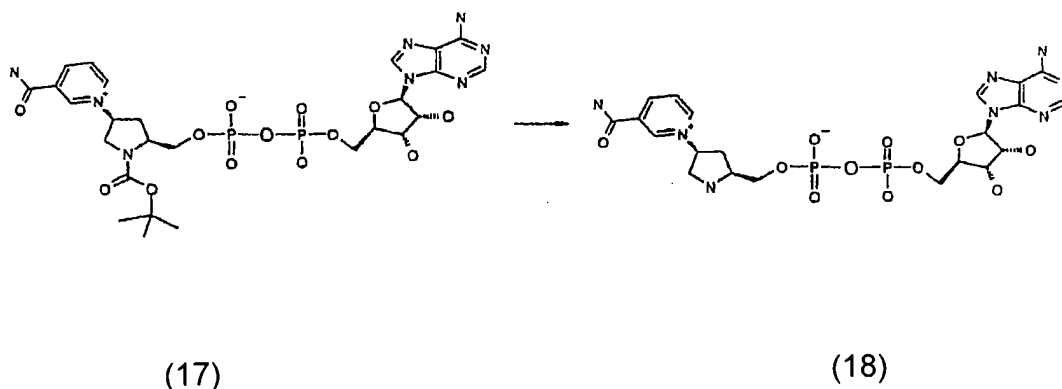
MS ESI ES – 729.3 = product, ES – 415 = cation of AMP morpholidate, ES – 400.2 / ES + 402.1 residues of compound 15 (stage 6)

TLC RP 8 F254 Rf 0.085

- 15 * In order to prepare this solution 2516 mg anhydrous MnCl_2 was dissolved in 100 ml 99.99 % formamide while stirring and subsequently 4A molecular sieve was added.

** The residue was further processed as a crude product.

VIII. Synthesis of pNAD 8th stage (compound 18, pyrrolidinyI-NAD)



5.0 ml trifluoroacetic acid (TFA) was added to 500 mg compound 17 from stage 7 (crude product, contains about 50 % salts) and stirred for 1 h at room temperature and subsequently concentrated by evaporation. 500 ml colourless oil was formed as the residue

MS ESI ES – 729.24 (addition of NH_3 necessary)

2 Portions of 200 mg and 300 mg were each purified in 2 separation steps:

10 First separation step:

Fractogel EMD SO3-s column: D (inner) = 14 mm L (packing) = 85 mm

I. Conditioning

(flow rate 5 ml/min) a) 100 ml H_2O

b) 200 ml 0.25 M H_2SO_4

15 c) 100 ml H_2O

d) 200 ml 1 M ammonia solution

e) 100 ml H_2O

II. Separation:

a) apply 200 ml substance dissolved in 5 ml H_2O

b) elute with a gradient of $\text{H}_2\text{O} \rightarrow 0.2 \text{ M } \text{NH}_4\text{HCO}_3$

20

solution. (mobile solvent A = 250 ml H_2O placed in an Erlenmeyer flask and stirred on a magnetic stirrer, pumped onto the column at a rate of 5 ml/min

mobile solvent B = 0.2 M NH_4HCO_3 solution
pumped at 2.5 ml/min to A).

III. Fractionation: a) fractions each of 3 ml

b) 1st peak impurities

5 c) 2nd peak after about 70 ml preliminary eluate =
substance

IV. Reconditioning: a) 100 ml 1 M ammonium solution

b) 100 ml H_2O

2nd separation step:

10 Diaion HP20, column D (inner) = 30 mm L (packing) 130 mm eluted with
100 ml H_2O and 100 ml H_2O / 5 % isopropanol.

The substance already elutes with the water phase; only impurities are
present in the isopropanol fraction.

3 fractions were obtained according to analytical HPLC: F1 = 13.5 mg

15 F2 = 5.5 mg

F3 = 11.5 mg

Total = 30.5 mg = 12.2 %

The identity of the pyrrolidinyI NAD (compound 18) was confirmed by NMR
analyses.

20 **Glucose dehydrogenase assay for pNAD**

In order to examine the role of pNAD as a cofactor for glucose
dehydrogenase (GlucDH), a glucoseDH activity assay in 0.1 M Tris/0.2 M
NaCl (pH 8.5) buffer was carried out. The concentration of glucose was
80 mM. pNAD and NAD concentrations of 0.05-0.5 mM were used. 10 mg/ml
25 (pNAD) or 0.002 mg/ml (NAD) [83 or 0.017 μM respectively] GlucDH was
added. The assay was carried out at room temperature and the enzymatic

reaction was monitored by recording absorption spectra at regular time intervals. The values shown in table 1 refer to an absorption measurement after 4 min.

Table 1

(p)NAD (mM)	U/ml	% activity	[GlucDH] used
0.05 NAD	539	100	0.02 mg/ml
0.4 NAD	1556	100	0.002 mg/ml
0.05 pNAD	0.0017	0.00003	10 µl 10 mg/ml
0.4 pNAD	0.0024	0.00015	10 µl 10 mg/ml

5

Absorption spectra of pNAD and pNADH

Absorption spectra of NAD and pNAD or NADH and pNADH are shown in figures 6A and 6B. NAD and pNAD exhibit an absorption maximum at 260 nm. pNADH i.e. pNAD after the GlucDH activity assay exhibits a red shift of the absorption maximum by about 10 nm (figure 6B) compared to NADH.

10

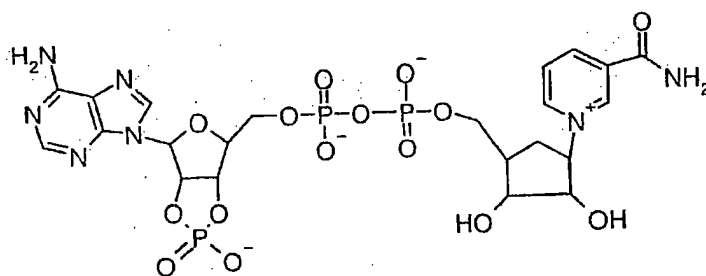
Fluorescence spectra of NADH and pNADH as GlucDH complexes are additionally shown in figures 7 and 8. The spectra were in each case recorded after the GlucDH activity assay. Figure 7 shows emission spectra of NADH / pNADH-GlucDH complexes at excitation wavelengths of 340 and 370 nm. The emission spectra of NADH and pNADH at 370 nm excitation wavelength are similar. Figure 8 shows an excitation spectrum for an NADH / pNADH-GlucDH complex at an emission wavelength of 460 nm. pNADH exhibits a broader excitation spectrum than NADH. The spectra were also recorded after GlucDH activity assays.

15

Investigation of the stability of pNAD

In order to examine the stability of pNAD compared to NAD, the same amounts of NAD and pNAD were each taken up in 0.15 M KPO₄, 1 M NaCl buffer (pH 7.0) and incubated at 50°C. The decomposition of NAD and pNAD were monitored by HPLC. Figure 9 shows the percentage areas of the (p)NAD amounts compared to the (p)NAD amounts at time zero. The figure shows that pNAD is very stable compared to NAD.

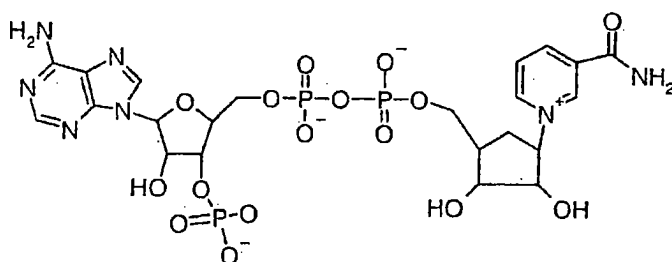
C) Preparation of carbaNAD cyclophosphate (19)



- 79 mg (0.1 mmol) O5'-(hydroxy-morpholino-phosphoryl)-O_{2'},O_{3'}-hydroxy-phosphoryl-adenosine, N-cyclohexyl-morpholine-4-carbonimidic acid cyclohexylamine salt dihydrate (dried by coevaporation with pyridine (Morhat et al., J. Am. Chem. Soc. 83; 1961; 663-675), 44 mg (0.105 mmol) carbaNMN monophosphate and subsequently 25 mg dry magnesium sulfate were added to 0.74 ml of a 0.2 manganese chloride solution in absolute formamide. The mixture was stirred under argon for three days in a closed reaction vessel and subsequently added to 10 ml acetonitrile while stirring. The precipitate was removed by filtration, purified by RP chromatography on a RP 18 Hypersil ODS, 250 x 21.2 mM, 5 µm column using a 0 % B to 100 % B gradient for 60 min: Eluant A: 0.1 M triethylammonium acetate, eluant B: 1:4 mixture of 0.1 M triethylammonium acetate and acetonitrile, flow rate: 10 ml/min. The elution was monitored by detection of 260 nm. The main

fraction was collected and lyophilized 5 times in order to remove the triethylammonium acetate. The triethylammonium salt was converted into the free acid with Dowex 50 WX2 and subsequently into the lithium salt. Yield: 10 mg.

5 **D) Preparation of carbaNADP (20)**



Three times four units ribonuclease T2 were added within 6 h at 37°C to a solution of 2.2 mg carbaNAD cyclophosphate lithium salt (19) in 1 ml bis-Tris-propane buffer (0.02 M, pH 7.5). The mixture was kept overnight at 37°C. The enzyme was denatured by heating to 65°C for 20 min. After filtration a purification was carried out by RP chromatography on a RP 18 Hypersil ODS, 250 x 21.2 mm, 5 µm column using a gradient of 0 % B to 100 % B for 60 min. Eluant A: 0.1 M triethylammonium acetate; eluant B: 1:4 mixture of 0.1 ml triethylammonium acetate and acetonitrile; flow rate: 10 ml/min. The elution was monitored by detection at 260 nm. The main fraction was collected and lyophilized 5 times in order to remove the triethylammonium acetate.

Mass spectrum (MALDI Applied Biosystems Voyager System 6327: calculated 742.45, found: 743.17).

E) Glucose dehydrogenase activity assay for cNAD

A glucose dehydrogenase activity assay for cNAD compared to NAD was carried out as described under B) for pNAD. For this purpose glucose dehydrogenase concentrations of 0.1 (cNAD) and 0.002 mg/ml (NAD) [0.83 and 0.017 μ M respectively] were used. The amounts used and the results are shown in table 2.

Table 2

(c)NAD (mM)	U/ml	% activity	[GlucDH] used
0.05 NAD	430	100	0.002 mg/ml
0.1 NAD	556	100	0.002 mg/ml
0.05 cNAD	2.7	0.63	0.1 mg/ml
0.1 cNAD	5.3	0.95	0.1 mg/ml

F) Absorption spectra of cNAD and cNADH

Figures 10A, 10B and 10C show absorption spectra of NAD and cNAD. NAD as well as cNAD have an absorption maximum at 260 nm. Figure 10B shows absorption spectra of NADH and cNADH where the spectra were in each case recorded after a glucose dehydrogenase activity assay. The absorption maximum of cNADH exhibits a red shift of 20 nm. Further absorption spectra for NADH and cNADH are shown in figure 10C in which different conditions for the associated glucose dehydrogenase activity assay were selected as stated in the legends.

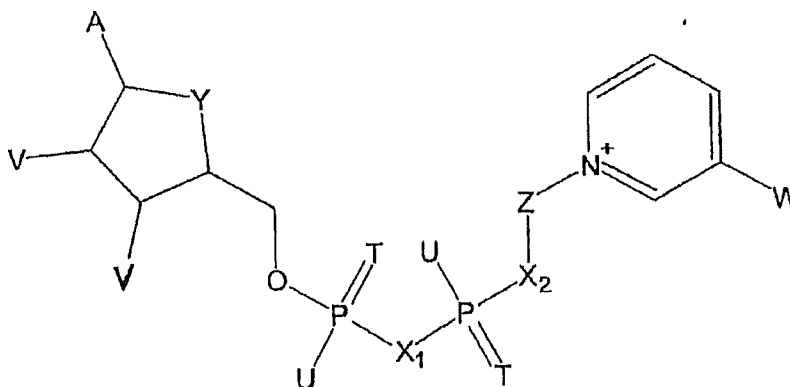
Figure 11 additionally shows fluorescence spectra of NADH and cNADH as GlucDH complexes. The spectra were recorded at an excitation wavelength of 370 nm after a glucose dehydrogenase activity assay. NADH as well as

cNADH exhibit an increase of the fluorescence signal when treated with GlucDH.

WHAT IS CLAIMED IS:

5

1. Test element for determining glucose, comprising (i) a glucose dehydrogenase and (ii) a compound of the following general formula (I) as the coenzyme:



10

(I)

in which

A = adenine or an analogue thereof,

T = in each case independently denotes O, S,

U = in each case independently denotes OH, SH, BH₃⁻, BCNH₂⁻,

15

V = in each case independently denotes OH or a phosphate group,
wherein in case that one residue V is an OH group and the
second residue V is a phosphate group, the OH group and the
phosphate group can form a ring together with the carbon
atoms to which they are attached,

20

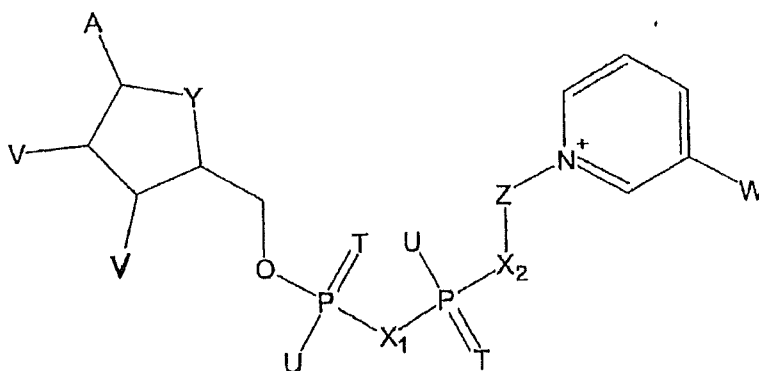
W = COOR, CON(R)₂, COR, CSN(R)₂ in which R in each case
independently denotes H or C₁-C₂-alkyl,

X₁, X₂ = in each case independently denote O, CH₂, CHCH₃, C(CH₃)₂,
NH, NCH₃,

Y = NH, S, O, CH₂,

Z = a residue comprising a cyclic group with 5 C atoms which optionally contains a heteroatom selected from O, S and N and optionally one or more substituents, and a residue CR₄₂ wherein CR₄₂ is bound to the cyclic group and to X₂,
 5 where R₄ = in each case independently denotes H, F, Cl, CH₃, provided that Z and the pyridine residue are not linked by a glycosidic bond,
 or a salt or optionally a reduced form thereof.

2. Test element according to claim 1,
 10 characterized in that
 the substituents on Z are selected from the group comprising F, Cl and C₁-C₂-alkyl which is optionally fluorinated or chlorinated or/and OH-substituted, O-C₁-C₂-alkyl.
3. Test element according to claim 1 to 2, comprising a compound of the
 15 following formula (I') as the coenzyme:



(I')

in which

- 20 A = adenine or an analogue thereof,
 T = in each case independently denotes O, S,
 U = in each case independently denotes OH, SH, BH₃⁻, BCNH₂⁻,
 V = in each case independently denotes OH or a phosphate

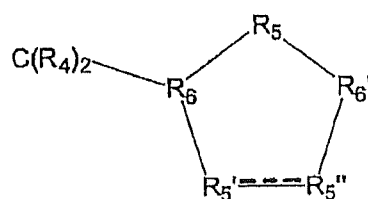
group,

W = COOR, CON(R)₂, COR, CSN(R)₂ in which R in each case independently denotes H or C₁-C₂-alkyl,

X1, X2 = in each case independently denote O, CH₂, CHCH₃, C(CH₃)₂,
 5 NH, NCH₃,

Y = NH, S, O, CH₂,

Z = a saturated or unsaturated carbocyclic or heterocyclic five-membered ring of the general formula (II)



(II)

in which a single or double bond can be present between R₅ and R₅'', in which

R₄ = in each case independently denotes H, F, Cl, CH₃,

R₅ = CR₄₂,

15 if a single bond is present between R₅' and R₅'', then

R₅' = O, S, NH, NC₁-C₂-alkyl, CR₄₂, CHOH, CHOCH₃,

R₅'' = CR₄₂, CHOH, CHOCH₃,

if a double bond is present between R₅' and R₅'',

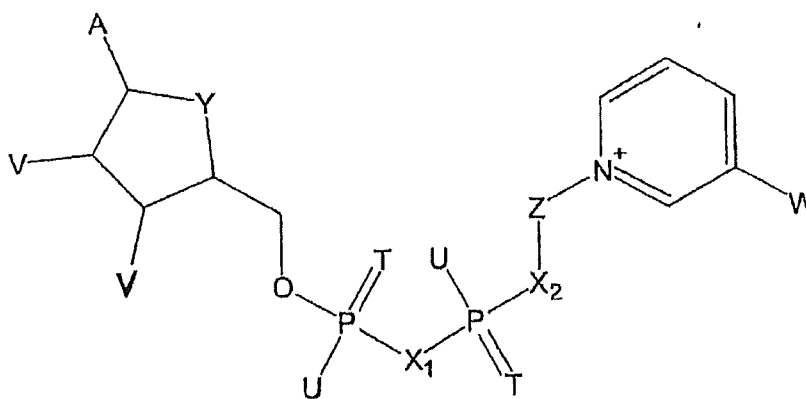
then R₅' = R₅'' = CR₄,

20 R₆, R₆' = in each case independently denote CH, CCH₃
 or a salt or optionally a reduced form thereof.

4. Test element according to any one of claims 1 to 3 in which
 W = CONH₂ or COCH₃.

5. Test element according to any one of claims 1 to 4 in the form of a test
 25 strip.

6. Compound of the general formula (I''):



(I'')

in which

A = adenine or an analogue thereof,

T = in each case independently denotes O, S,

U = in each case independently denotes OH, SH, BH_3^- , BCNH_2^- ,

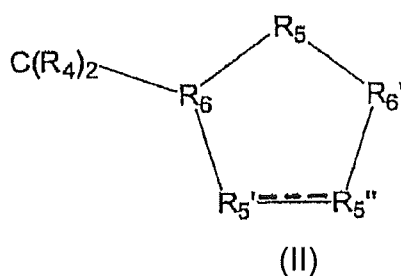
V = in each case independently denotes OH or a phosphate group, wherein in case that one residue V is an OH group and the second residue V is a phosphate group, the OH group and the phosphate group can form a ring together with the carbon atoms to which they are attached,

W = COOR, $\text{CON}(\text{R})_2$, COR, $\text{CSN}(\text{R})_2$ in which R in each case independently denotes H or C_1 - C_2 -alkyl,

X1, X2 = in each case independently denote O, or NH,

Y = NH, S, O, CH_2 ,

Z = a saturated or unsaturated carbocyclic or heterocyclic five-membered ring of the general formula (II)



in which a single or double bond can be present between R5' and R5'',

R4 = in each case independently denotes H, F, Cl, CH₃,

R5 = CR₄₂,

if a single bond is present between R5' and R5'', then

R5' = O, S, NH, NC₁-C₂-alkyl, CR₄₂, CHOH, CHOCH₃,

R5'' = CR₄₂, CHOH, CHOCH₃,

if a double bond is present between R5' and R5'',

then R5' = R5'' = CR₄,

R6, R6' = in each case independently denote CH, CCH₃

provided that if R5 = CH₂, T = O, U = in each case OH, V =

OH, W = CONH₂, X₁, X₂ = O and Y = O, then R5' and R5'' are not simultaneously CHOH,

or a salt or optionally a reduced form thereof.

7. Compound according to claim 6,
characterized in that

at least one residue U is different from OH.

8. Compound according to claim 6 or 7,
characterized in that
at least one residue U = BH₃⁻.

9. Compound according to any one of claims 6 to 8 in which
W = CONH₂ or COCH₃.

10. Compound according to any one of claims 6 to 9,

in which a first residue V is an OH group and a second residue V is a phosphate group.

11. Compound according to any one of claims 6 to 9,
in which $R5' = CR_4$ or CHOH.
- 5 12. Compound according to any one of claims 6 to 9,
in which $R5'$ is O.
13. Compound according to any one of claims 6 to 9,
in which $R5' = NH$ or NC_1-C_2 -alkyl.
14. Compound according to any one of claims 6 to 9,
10 which is carbaNADP or a salt or a reduced form thereof.
15. Enzyme-coenzyme complex
consisting of a compound according to any one of claims 6 to 14 in
combination with an enzyme.
16. Complex according to claim 15,
15 characterized in that
the enzyme is a dehydrogenase selected from glucose dehydrogenase
(E.C.1.1.1.47), lactate dehydrogenase (E.C.1.1.1.27, 1.1.1.28), malate
dehydrogenase (E.C.1.1.1.37), glycerol dehydrogenase (E.C.1.1.1.6),
alcohol dehydrogenase (E.C.1.1.1.1), alpha-hydroxybutyrate
20 dehydrogenase, sorbitol dehydrogenase or amino acid dehydrogenase
selected from L-amino acid dehydrogenase (E.C.1.4.1.5).
17. Use of a compound according to any one of claims 6 to 14 or a
complex according to claim 15 or 16 to detect an analyte in a sample
by an enzymatic reaction.
- 25 18. Reagent kit containing a compound according to any one of claims 6 to
14 and optionally an enzyme or an enzyme-coenzyme complex
according to claim 15 or 16 as well as a reaction buffer.

19. Reagent kit according to claim 18,
characterized in that
the enzyme is a dehydrogenase selected from glucose dehydrogenase
(E.C.1.1.1.47), lactate dehydrogenase (E.C.1.1.1.27, 1.1.1.28), malate
5 dehydrogenase (E.C.1.1.1.37), glycerol dehydrogenase (E.C.1.1.1.6),
alcohol dehydrogenase (E.C.1.1.1.1), alpha-hydroxybutyrate
dehydrogenase, sorbitol dehydrogenase or amino acid dehydrogenase
selected from L-amino acid dehydrogenase (E.C.1.4.1.5).
20. Use of the test element according to any one of claims 1 to 5 or of the
10 reagent kit according to claim 18 or 19 to determine analytes selected
from glucose, lactic acid, malic acid, glycerol, alcohol, cholesterol,
triglycerides, ascorbic acid, cysteine, glutathione, peptides, urea,
ammonium, salicylate, pyruvate, 5'-nucleotidase, creatine kinase (CK),
lactate dehydrogenase (LDH) and carbon dioxide.
- 15 21. Method for detecting an analyte comprising the steps:
(a) contacting a sample with a test element according to any one of
claims 1 to 5 or a reagent kit according to claim 18 or 19,
comprising a coenzyme and
(b) detecting the analyte.
- 20 22. Method according to claim 21,
characterized in that
the analyte is detected photometrically or fluorometrically.