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Method and reagent system with non-regenerable enzyme-coenzyme complex

Description

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The invention relates to a method and a reagent system for detecting an analyte in a sample through an enzymatic reaction, comprising the use of an enzyme-coenzyme complex as non-regenerable, in particular stoichiometric reactant for the analyte present in the sample.

The detection of analytes, for example glucose in blood, by enzymatic methods is known. These entail the analyte to be determined being brought into contact with a suitable enzyme and a coenzyme, the enzyme being employed in catalytic amounts. The redox equivalents produced on reduction or oxidation of the coenzyme are transferred to mediators which are then detected electrochemically or photometrically in a further step. A calibration provides a direct connection between the measurement and the concentration of the analyte to be determined.

Sierra et al. (Anal. Chem. 69 (1997), 1471-1476) describe a determination of blood glucose based on the intrinsic fluorescence of glucose oxidase. In this method too, the enzyme is employed together with its coenzyme FAD in catalytic amounts, with redox equivalents being transferred to oxygen as mediator.

Narayanaswamy et al. (Analytical Letters 21 (7) (1988), 1165-1175) describe a fluorescence measurement with glucose dehydrogenase and NAD for glucose determination. The enzyme is in this case employed in catalytic, i.e. non-stoichiometric, amounts. The fluorescence measurement detects the free NADH in the solution.

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It is possible through the electrochemically active substances (mediators) required for the prior art detection systems to detect the analytes to be determined only indirectly, i.e. via a plurality of
5 chemical reactions. For this purpose, a complicated adjustment of the concentrations of the substances involved to optimize the reaction rate is often necessary. There is moreover the risk that the required electrochemically active substances are unstable on
10 prolonged storage.

The mediators often also have to be employed in large excess relative to the enzyme-coenzyme system. The coenzyme has a high reactivity, so that the enzymic
15 activity declines markedly on decomposition of the mediator, even in small amounts, e.g. < 1% or on exposure to foreign substances, e.g. volatilization of the substances from packaging materials. This may lead to false signals in the determination of the analyte.
20 Yet a further disadvantage is that the determination times for the analytes are normally in the region of at least a few seconds, for example for glucose in the region of > 4 s, and the required sample volumes are large, e.g. > 0.5 µl.

25 The object on which the present invention was based is at least partly to avoid the described disadvantages of the prior art. It was particularly intended to provide a non-sensitive and rapid method for the enzymatic
30 detection of analytes, which leads to reliable measurement results even in the absence of mediators or/and indicators.

This object is achieved by using an enzyme-coenzyme
35 complex as stoichiometric reactant instead of, as usual, as catalyst. Detection of the analyte requires only a single reaction step and is therefore extremely fast. The use of mediators and indicators, associated with the employment of complex reaction mixtures, with

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low stability and high susceptibility to interference, is no longer necessary.

One aspect of the invention is thus a method for
5 detecting an analyte in a sample by an enzymatic reaction, comprising the steps:

- (a) contacting the sample with a detection reagent comprising an enzyme-coenzyme complex, where no regeneration of the coenzyme takes place, and
- 10 (b) detecting a reaction of the analyte through a change in the enzyme-coenzyme complex.

A further aspect of the invention is a reagent system for detecting an analyte in a sample, comprising:

- 15 (a) a detection reagent comprising an enzyme-coenzyme complex, where no regeneration of the coenzyme takes place, and
- (b) a support to receive the detection reagent.

20 The present invention makes a simple qualitative or quantitative determination of analytes possible within a very short reaction time of, preferably, ≤ 5 s, particularly preferably ≤ 1 s, most preferably ≤ 0.1 s. The reaction is carried out under conditions with which
25 no regeneration of the coenzyme takes place during the determination. It is moreover possible for a molecule enzyme-coenzyme complex to react only with a single molecule of the analyte. The reaction is therefore expediently carried out in the absence of mediators or
30 other substances able to bring about regeneration of the coenzyme.

The detection reagent comprises the enzyme-coenzyme complex in an amount sufficient to make qualitative
35 or/and quantitative determination of the analyte possible according to the desired test format. In particular, for quantitative determination of the analyte, the enzyme-coenzyme complex is employed in an amount such that the number of reacting molecules of

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the enzyme-coenzyme complex correlates with the analyte concentration present in the sample. The enzyme-coenzyme complex is particularly preferably employed in an at least stoichiometric amount relative to the analyte present in the sample, preferably in a stoichiometric excess relative to the analyte. In this connection, the statement "in at least a stoichiometric amount" means that the size of the sample is adjusted relative to the number of molecules of the enzyme-coenzyme complex in such a way that, with the analyte concentrations to be expected in the sample, the number of molecules of the enzyme-coenzyme complex which react with the analyte correlates with the analyte concentration present in the sample. "Stoichiometric amount" preferably means that the number of molecules of the enzyme-coenzyme complex corresponds to the maximum number of analyte molecules to be expected in the investigative sample.

The method and the detection system permit the use of very small amounts of sample, for example sample volumes of $\leq 1 \mu\text{l}$, in particular $\leq 0.1 \mu\text{l}$. The sample can where appropriate also be diluted before contacting with the detection reagent.

The method and detection system of the invention is suitable for determining any analytes, for example parameters in body fluids such as, for example, blood, serum, plasma or urine, but also in effluent samples or foodstuffs. The method can also be carried out as wet test, e.g. in a cuvette, or as dry test on an appropriate reagent support.

The analytes which can be determined are any biological or chemical substances which are able to undergo a reaction, in particular a redox reaction, with an enzyme-coenzyme complex, such as, for example, glucose, lactic acid, malic acid, glycerol, alcohol,

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cholesterol, triglycerides, ascorbic acid, cysteine, glutathione, peptides etc.

5 The enzymatic reaction is preferably a redox reaction in which the coenzyme in the enzyme-coenzyme complex is reduced or oxidized. The enzyme preferably used for a reaction of this type is an oxidoreductase. The enzyme particularly preferably used is a dehydrogenase, for example selected from a glucose dehydrogenase
10 (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) or amino-acid dehydrogenase, e.g. L-amino-acid dehydrogenase (E.C.1.4.1.5). Further suitable
15 enzymes are oxidases such as, for example, glucose oxidase (E.C.1.1.3.4) or cholesterol oxidase (E.C.1.1.3.6).

Coenzymes for the purposes of the present invention are
20 preferably organic molecules which are linked covalently or noncovalently to an enzyme and are changed, for example oxidized or reduced, by the conversion of the analyte. Preferred examples of coenzymes are flavin, nicotine and quinone derivatives,
25 for example flavin nucleoside derivatives such as, for example, FAD, FADH₂, FMN, FMNH₂, etc., nicotine nucleoside derivatives such as, for example, NAD⁺, NADH/H⁺, NADP⁺, NADPH/H⁺ etc. or ubiquinones such as, for example, coenzyme Q, PQQ etc.

30 The change in the coenzyme through reaction with the analyte can in principle be detected in any manner. It is possible in principle to employ for this all methods known in the art for detecting enzymatic reactions.
35 However, the change in the coenzyme is preferably detected by optical methods. Optical detection methods include for example measuring absorption, fluorescence, circular dichroism (CD), optical rotary dispersion (ORD), refractometry etc. The change in the coenzyme is

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particularly preferably detected by measuring the fluorescence. The fluorescence measurement is highly sensitive and makes it possible to detect even low concentrations of the analyte in miniaturized systems.

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The method or detection system of the invention may comprise a liquid test, in which case the reagent is present for example in the form of a solution or suspension in an aqueous or nonaqueous liquid or as
10 powder or lyophilizate. However, the method and detection system of the invention preferably comprises a dry test, in which case the reagent is applied to a support. The support may comprise for example a test strip comprising an absorbent or/and swellable material
15 which is wetted by the sample liquid to be investigated.

In a particularly preferred embodiment, the detection reagent used is a gel matrix with an enzyme-coenzyme
20 complex embedded therein. The gel matrix preferably has a layer thickness of $\leq 50 \mu\text{m}$, in particular $\leq 5 \mu\text{m}$, and is applied to a support, for example an at least partly optically transparent support. The gel matrix may be a matrix comprising one or more soluble polymers, as in
25 known dry test systems (e.g. AccuChek Active), and can be produced by knife application and drying. The matrix is preferably a polymer with a structure based on photopolymerizable substances such as, for example, acrylic monomers, e.g. acrylamide or/and acrylic esters
30 such as polyethylene glycol diacrylate, or vinylaromatic monomers, e.g. 4-vinylbenzenesulfonic acid, or combinations thereof. A gel matrix of this type can be produced by applying a liquid which contains the reagent, comprising enzyme, photopolymerizable monomer
35 and, where appropriate, coenzyme, photoinitiator or/and unreactive constituents, to an at least partly optically transparent support, for example to a plastics sheet, and irradiating, for example with UV light from the reverse side, so that polymerization of

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the monomer or of the monomers takes place on the support up to a predefined layer thickness. The layer thickness can be controlled by adding absorbing substances to the reagent or/and through the duration
5 or intensity of irradiation. Excess liquid reagent can be removed and reused after the polymerization (see, for example, figure 2).

On the other hand, the gel matrix can also be produced
10 by conventional coating procedures, in which case the liquid reagent is applied to a support, brought to the desired thickness using suitable methods, e.g. using a knife, and then completely polymerized.

15 After inclusion by polymerization or embedding in the gel matrix, the enzyme is in a protected micro-environment. If the polymeric gel matrix is sufficiently crosslinked, the enzyme molecules are present in an immobilized form. Low molecular weight
20 substances or glucose or other analytes or else coenzymes can, however, diffuse freely through the polymer network.

The enzyme can either be included together with its
25 coenzyme by polymerization in the matrix or, after the polymerization, the matrix can be brought into contact with a solution of the coenzyme, so that the appropriate enzyme-coenzyme complex is formed. The concentration of the enzyme in the gel matrix is
30 preferably chosen to be high enough for a stoichiometric reaction with the analyte to be determined, and a direct determination of the coenzyme which is changed by the reaction, to be possible. The reaction consists only of a single catalytic reaction, for example, a
35 redox reaction, which can take place in the region of milliseconds or microseconds. The coenzyme which is changed by the reaction is optimally protected from interfering influences through binding to the active

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center of the enzyme and, where appropriate, additionally by embedding in the gel matrix.

The invention is additionally to be explained by the
5 following figures and examples.

Figures

Figure 1 shows a first embodiment of the detection
10 system of the invention. A reagent layer (2), e.g. a
gel matrix with an enzyme-coenzyme complex, is applied
to an optically transparent support (1). The enzyme-
coenzyme complex is in a form such that no regeneration
15 of the coenzyme can take place during the analyte
determination. A sample (3), e.g. blood, is put on the
reagent layer. Determination of the enzymatic reaction
between the analyte contained in the sample (3), and
the enzyme-coenzyme complex contained in the reagent
20 layer (2) takes place by optical methods. Light from a
light source (4), e.g. a laser or an LED, is beamed
from behind (through the support) onto the reagent
layer (2). Absorption light or fluorescent light beamed
back from the sample is detected in a detector (5).
Where appropriate - in particular for detecting
25 fluorescent light - an optical filter element (6) is
put in front of the detector in order to block leakage
of the fluorescence-exciting light.

Figure 2 shows the production of a detection system of
30 the invention. A liquid reagent (12) is applied, for
example in a first position (13), to an optically
transparent support (11), e.g. a plastics sheet. The
liquid reagent (12) is irradiated at a second position
from below through the support (11) with light from a
35 light source (14). At the same time, the support is
moved in the direction (15) identified by the arrow. A
polymerized reagent layer (16) is formed directly on
the support (11). Excess liquid reagent is present
above the polymer layer (16). The thickness of the

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polymerized reagent layer (16) can be controlled through the reagent composition, the duration and intensity of the beaming in of light, and through the properties of the support (11).

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Figure 3 shows an embodiment of a fluorescence-based sensor from below. A polymerized reagent layer, for example one produced by the continuous process in Figure 2, can be cut and applied to a support (21) by use of known techniques. After application of the sample to the upper side, exciting light (23), e.g. UV light, is beamed in from a light source from below. The fluorescence (24), e.g. blue light, generated through the reaction of the analyte with the enzyme-coenzyme complex in the reagent layer (22) is detected with a detector.

It is also possible for a plurality of (identical or different) reagents to be applied to a support. One example of such an embodiment in the form of a disk is shown in **figure 4**. A plurality of reagent spots (32) is disposed on the optically transparent support (31).

Figures 5A and 5B show the fluorescence of a detection system of the invention (glucose dehydrogenase and NAD^+) with increasing glucose concentration under a CCD camera.

Examples

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Example 1: Stoichiometric detection of glucose in the glucose dehydrogenase (GlucDH)/ NAD^+ system in a cuvette

100 mg/ml GlucDH are dissolved in buffer of pH 7 and mixed with the appropriate amount of NAD^+ . On addition of increasing amounts of glucose, an increase in the fluorescence can be detected visually under a UV lamp (excitation wavelength 366 nm) (figures 5A and 5B).

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The solution with the enzyme system does not fluoresce without glucose. Nor do glucose and NAD^+ result in any fluorescence.

5 **Example 2: Detection of glucose in the GlucDH/ NAD^+ system in a polymer film**

A suspension of the following substance was mixed in a plastic test tube

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Formula 1

Substance	Amount [g]	Weight [%]
Acrylamide	2.5	22.02
Methylenebisacrylamide	0.7	6.17
2,2-Dimethoxy-2-phenylacetophenone	0.05	0.44
Glycerol	5	44.05
Hydroxyethyl methacrylate	1.4	12.33
Methyl methacrylate	0.4	3.52
Crodasinc O solution, pH 8, 0.3 g/1000 ml	1	8.81
N,N'-(1,2-Dihydroxyethylene)bisacrylamide	0.3	2.64
TOTAL	11.35	100

0.5 ml of this suspension were mixed with 0.5 ml of a
15 solution of GlucDH (100 mg/ml), and the mixture was
homogenized free of air bubbles in an ultrasonic bath.

The clear solution was poured onto a corona-treated
polycarbonate sheet 125 mm thick and illuminated with a
20 conventional illumination apparatus (Isel UV
illumination device 2) for 20 min. The sheet was
briefly washed with water and then dried in the air.

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The resulting layer thickness was $< 2 \mu\text{m}$. A freshly prepared glucose/ NAD^+ solution (GKL-3 solution, 300 mg/dl glucose, 1 ml/6.4 mg of NAD^+) was spotted on the film. A strong fluorescence was immediately visible under a UV lamp.

Example 3: Adding a UV absorber to influence the layer thickness

A polymer layer comprising a blue dye (absorption maximum $\approx 650 \text{ nm}$) for better identification was produced (formula 2). In a further experiment, a yellow dye was admixed as UV absorber to the initial formula (formula 3).

Formula 2

Substance	Amount	Weight [%]
Acrylamide	37.5 g (0.53 mol)	25.78
Polyethylene glycol diacrylate, Mw $\approx 575 \text{ g/mol}$	52.5 g (ca. 0.96 mol)	36.10
Solution of Crodasinic O (0.3 g/1 l)	50 g	34.38
4-Vinylbenzenesulfonic acid	5 g	3.44
2,2-Dimethoxy-2-phenylacetophenone photoinitiator	350 mg	0.24
New methylene blue N	100 mg	0.06
TOTAL	145.45 g	100

The mixture was homogenized by stirring and by ultrasonic bath treatment, distributed with a pipette on a $140 \mu\text{m}$ Pokalon sheet (corona-treated, stage 4) and illuminated in a UV illumination device (Actina U4, W. Lemmen GmbH) for 1 min.

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The resulting layer thickness was measured with a screw gage and was 240.5 μm .

Formula 3

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Substance	Amount	Weight [%]
Formula 2	1 ml	ca. 99.99
Mordant Yellow 7 (No. 686) (UV absorber)	0.0001 g	0.001
TOTAL	ca. 1.0001 g	100

The mixture was distributed on a sheet and then polymerized as described above. The resulting layer thickness was measured with a screw gage and was

10 79.3 μm .

This experiment shows that it is possible to influence the layer thickness. With reaction conditions which were otherwise the same, the layer thickness without UV

15 absorber is 240.5 μm (see above); only 79.3 μm with UV absorber (Mordant Yellow 7).

Claims

1. A method for detecting an analyte in a sample by an enzymatic reaction, comprising the steps:
 - 5 (a) contacting the sample with a detection reagent comprising an enzyme-coenzyme complex, under conditions with which no regeneration of the coenzyme takes place, where a dehydrogenase is used as enzyme, and
 - 10 (b) detecting a reaction of the analyte through a change in the enzyme-coenzyme complex.
2. The method as claimed in claim 1, characterized in that the dehydrogenase is selected from a glucose
15 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) or amino-acid dehydrogenase, e.g.
20 L-amino-acid dehydrogenase (E.C.1.4.1.5).
3. The method as claimed in any of the preceding claims, characterized in that a coenzyme selected from flavin, nicotine and quinone derivatives is
25 used.
4. The method as claimed in claim 3, characterized in that the coenzyme is selected from FAD, FADH₂, FMN, FMNH₂, coenzyme Q, PQQ, NAD⁺, NADH/H⁺, NADP⁺
30 and NADPH/H⁺.
5. The method as claimed in claim 1 to 4, characterized in that the change in the coenzyme is detected by optical methods.
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6. The method as claimed in claim 5, characterized in that the change in the coenzyme is detected by

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measuring absorption, fluorescence, CD, ORD or refractometry.

- 5 7. The method as claimed in claim 6, characterized in that the change in the coenzyme is detected by measuring the fluorescence.
- 10 8. The method as claimed in any of the preceding claims, characterized in that a gel matrix with an enzyme-coenzyme complex embedded therein is used as detection reagent.
- 15 9. The method as claimed in claim 8, characterized in that the gel matrix has a layer thickness of $\leq 50 \mu\text{m}$, in particular of $\leq 5 \mu\text{m}$.
- 20 10. The method as claimed in claim 8 or 9, characterized in that a gel matrix based on photopolymerizable substances is used.
11. The method as claimed in any of the preceding claims, characterized in that an analyte in a body fluid is determined.
- 25 12. The method as claimed in claim 11, characterized in that a determination of glucose in blood is carried out.
- 30 13. The method as claimed in any of the preceding claims, characterized in that the duration of the reaction of the analyte is $\leq 5 \text{ s}$.
- 35 14. The method as claimed in any of the preceding claims, characterized in that the reaction is carried out in the absence of mediators able to react with the coenzyme.

15. The method as claimed in any of the preceding claims, characterized in that the enzyme-coenzyme complex is employed as stoichiometric reactant in relation to the analyte.
16. A reagent system for detecting an analyte in a sample, comprising:
 - (a) a detection reagent comprising an enzyme coenzyme complex in a form such that no regeneration of the coenzyme takes place during the reaction of the enzyme-coenzyme complex with the analyte, where a dehydrogenase is used as enzyme, and
 - (b) a support to receive the detection reagent.
17. The reagent system as claimed in claim 16, characterized in that the enzyme-coenzyme complex is embedded in a gel matrix.
18. The reagent system as claimed in claim 16 or 17, characterized in that the support is at least partly optically transparent.
19. The reagent system as claimed in any of claims 16 to 18, characterized in that the support comprises an essentially planar structure.
20. The reagent system as claimed in any of claims 16 to 18, characterized in that the support comprises a plurality of different detection reagents.
21. The use of a reagent system as claimed in any of claims 16 to 20 in a method as claimed in any of claims 1 to 15.