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BISPECIFIC ANTIBODIES COMPRISING A DISULFIDE STABILIZED - FV FRAGMENT

The present invention relates to trivalent, bispecific antibodies, methods for their production, pharmaceutical compositions containing said antibodies, and uses thereof.

Background of the Invention

5 A wide variety of multispecific recombinant antibody formats has been developed in the recent past, e.g. tetravalent bispecific antibodies by fusion of, e.g., an IgG antibody format and single chain domains (see e.g. Coloma, M.J., et al., Nature Biotech 15 (1997) 159-163; WO 2001/077342; and Morrison, S.L., Nature Biotech 25 (2007) 1233-1234).

10 Also several other new formats wherein the antibody core structure (IgA, IgD, IgE, IgG or IgM) is no longer retained such as dia-, tria- or tetrabodies, minibodies, several single chain formats (scFv, Bis-scFv), which are capable of binding two or more antigens, have been developed (Holliger, P., et al, Nature Biotech 23 (2005) 1126-1136; Fischer, N., and Léger, O., Pathobiology 74 (2007) 3-14; Shen, J., et al., Journal of Immunological Methods 318 (2007) 65-74; Wu, C., et al., Nature Biotech. 25 (2007) 1290-1297).

20 All such formats use linkers either to fuse the antibody core (IgA, IgD, IgE, IgG or IgM) to a further binding protein (e.g. scFv) or to fuse e.g. two Fab fragments or scFvs (Fischer, N., and Léger, O., Pathobiology 74 (2007) 3-14). It has to be kept in mind that one may want to retain effector functions, such as e.g. complement-dependent cytotoxicity (CDC) or antibody dependent cellular cytotoxicity (ADCC), which are mediated through the Fc receptor binding, by maintaining a high degree of similarity to naturally occurring antibodies.

25 A process for the preparation of biologically active antibody dimers is reported in US 6,897,044. Multivalent F_V antibody construct having at least four variable domains which are linked with each other via peptide linkers are reported in US 7,129,330. Dimeric and multimeric antigen binding structures are reported in US 2005/0079170. Tri- or tetra-valent monospecific antigen-binding protein comprising three or four Fab fragments bound to each other covalently by a connecting structure, which protein is not a natural immunoglobulin are reported in 30 US 6,511,663. In WO 2006/020258 tetravalent bispecific antibodies are reported

that can be efficiently expressed in prokaryotic and eukaryotic cells, and are useful in therapeutic and diagnostic methods. A method of separating or preferentially synthesizing dimers which are linked via at least one interchain disulfide linkage from dimers which are not linked via at least one interchain disulfide linkage from a mixture comprising the two types of polypeptide dimers is reported in US 2005/0163782. Bispecific tetravalent receptors are reported in US 5,959,083. Engineered antibodies with three or more functional antigen binding sites are reported in WO 2001/077342. In WO 2007/109254 stabilized binding molecules that consist of or comprise a stabilized scFv are reported.

In WO 2007/024715 are reported dual variable domain immunoglobulins as engineered multivalent and multispecific binding proteins.

WO 2011/034605 relates to engineered protein complexes constructed using a coiled coil and/or a tether and methods for making, using, and purifying such complexes, such as multispecific antibodies or other multispecific Fc containing complexes.

Summary of the Invention

The current invention relates to a bispecific antibody comprising

a) a full length antibody specifically binding to a first antigen and consisting of two antibody heavy chains and two antibody light chains;

b) a Fv fragment specifically binding to a second antigen comprising a VH² domain and a VL² domain, wherein both domains are connected via a disulfide bridge, and

wherein only either the VH² domain or the VL² domain is fused via a peptide linker to the heavy or light chain of the full length antibody specifically binding to a first antigen.

In one embodiment the bispecific antibody according to claim 1 characterized in that the bispecific antibody is trivalent and either the VH² domain or the VL² domain is fused via a peptide linker to the heavy chain of the full length antibody specifically binding to a first antigen.

In one embodiment the bispecific antibody according to claim 2 characterized in that

the VH² domain or VL² domain is N-terminally fused via a peptide linker to the C-terminus of the full length antibody specifically binding to a first antigen.

5 In one embodiment the bispecific antibody according to claims 2, characterized in that the bispecific antibody is trivalent and the VH² domain or VL² domain is C-terminally fused via a peptide linker to the N-terminus of the full length antibody specifically binding to a first antigen.

10 In one embodiment the bispecific antibody according to the invention is characterized in that the bispecific antibody is trivalent and the VH² domain or VL² domain is N-terminally fused via a peptide linker to the C-terminus of the heavy or light chain of the full length antibody specifically binding to a first antigen.

In one embodiment the bispecific antibody according to the invention is characterized in that

15 the VH² domain or VL² domain is C-terminally fused via a peptide linker to the N-terminus of the heavy or light chain of the full length antibody specifically binding to a first antigen.

In one embodiment the bispecific antibody according to the invention is characterized in that

20 the VH² domain or VL² domain is N-terminally fused via a peptide linker to the C-terminus of the heavy or light chain of the full length antibody specifically binding to a first antigen, or

the VH² domain or VL² domain is C-terminally fused via a peptide linker to the N-terminus of the heavy or light chain of the full length antibody

25 specifically binding to a first antigen.

In one embodiment the bispecific antibody according to the invention is characterized in that

the bispecific antibody is trivalent and either the VH² domain or the VL² domain is fused via a peptide linker to the heavy chain of the full length antibody

30 specifically binding to a first antigen.

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In one embodiment the trivalent, bispecific antibody according to the invention is characterized in that the VH² domain or VL² domain is N-terminally fused via a peptide linker to the C-terminus of the heavy chain of the full length antibody specifically binding to a first antigen.

5 In one embodiment the trivalent bispecific antibody according to the invention is characterized in that the VH² domain or VL² domain is C-terminally fused via a peptide linker to the N-terminus of the heavy chain of the full length antibody specifically binding to a first antigen.

10 In one embodiment the bispecific antibody according to the invention is characterized in that

the VH² domain and the VL² domain are connected via a disulfide bridge which is introduced between the following positions:

- 15 i) VH² domain position 44 and VL² domain position 100,
ii) VH² domain position 105 and VL² domain position 43, or
iii) VH² domain position 101 and VL² domain position 100.

(according to the Kabat numbering)

In one embodiment the bispecific antibody according to the invention is characterized in that

20 the VH² domain and the VL² domain are connected via a disulfide bridge which is introduced between
VH² domain position 44 and VL² domain position 100.

In one embodiment the bispecific antibody according to the invention is characterized in that

25 the first CH₃ domain of the heavy chain of the whole antibody and the second CH₃ domain of the whole antibody each meet at an interface which comprises an alteration in the original interface between the antibody CH₃ domains;

wherein i) in the CH₃ domain of one heavy chain,

30 an amino acid residue is replaced with an amino acid residue having a larger side chain volume, thereby generating a protuberance within the interface of

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the CH3 domain of one heavy chain which is positionable in a cavity within the interface of the CH3 domain of the other heavy chain

and

ii) in the CH3 domain of the other heavy chain,

- 5 an amino acid residue is replaced with an amino acid residue having a smaller side chain volume, thereby generating a cavity within the interface of the second CH3 domain within which a protuberance within the interface of the first CH3 domain is positionable.

10 One aspect of the invention is a method for the preparation of the bispecific antibody according to the invention comprising the steps of

A) expressing in a mammalian cell nucleic acid encoding a bispecific antibody comprising

- a) a full length antibody specifically binding to a first antigen and consisting of two antibody heavy chains and two antibody light chains;
- 15 b) a Fv fragment specifically binding to a second antigen comprising a VH² domain and a VL² domain, wherein both domains are connected via a disulfide bridge, and

wherein the Fv fragment is fused

20 via the N-termini of the VH² domain and the VL² domain to the both C-termini of the heavy chain of the full length antibody specifically binding to a first antigen via a first and second peptide linker to, or

25 via the C-termini of the VH² domain and the VL² domain to the both N-termini of one heavy and one light chain of the full length antibody specifically binding to a first antigen via a first and second peptide linker,

characterized in that

30 one of the linkers comprises a protease cleavage site cleavable by furin, and the other linker does not comprise a protease cleavage site;

B) recovering said antibody from said cell or the cell culture supernatant.

Another aspect of the invention is a method for the preparation of the trivalent, bispecific antibody according to the invention comprising the steps of

A) expressing in a mammalian cell nucleic acid encoding a bispecific antibody comprising

a) a full length antibody specifically binding to a first antigen and consisting of two antibody heavy chains and two antibody light chains;

b) a Fv fragment specifically binding to a second antigen comprising a VH^2 domain and a VL^2 domain, wherein both domains are connected via a disulfide bridge, and

wherein the Fv fragment is fused

via the N-termini of the VH^2 domain and the VL^2 domain to the both C-termini of the heavy chains of the full length antibody specifically binding to a first antigen via a first and second peptide linker to, or

via the C-termini of the VH^2 domain and the VL^2 domain to the both N-termini of the heavy chains of the full length antibody specifically binding to a first antigen via a first and second peptide linker,

characterized in that

one of the linkers comprises a protease cleavage site cleavable by Prescission protease, and the other linker does not comprise a protease cleavage site;

B) recovering said antibody from said cell or the cell culture supernatant.

In one embodiment the method is characterized in that

the protease cleavage site cleavable by furin is SEQ ID NO:13 or SEQ ID NO:14.

In one embodiment the method is characterized in that

the protease cleavage site cleavable by Prescission protease is SEQ ID NO:15.

In one embodiment the method is characterized in that

a mammalian cell, in one embodiment a CHO cell, NS0 cell, SP2/0 cell,

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HEK293 cell, COS cell, PER.C6 cell, in another embodiment a HEK293 cell or CHO cell.

One aspect of the invention is an antibody obtained by such recombinant methods.

5 One aspect of the invention is a pharmaceutical composition comprising the bispecific antibody according to the invention.

One aspect of the invention is the bispecific antibody according to the invention for the treatment of cancer.

One aspect of the invention is the use of the bispecific antibody according to the invention for the manufacture of a medicament for the treatment of cancer.

10 The invention further provides a method for treating a patient suffering from a disease like e.g. cancer or inflammation, comprising administering to a patient diagnosed as having such a disease (and therefore being in need of such a therapy) an effective amount of an antibody according to the invention. The antibody is administered preferably in a pharmaceutical composition.

15 The bispecific antibodies according to the invention on the one hand show valuable properties like biological activity due to their binding to different antigens. The disulfide stabilized Fv fragment binding to the second antigen shows excellent binding properties due to the high flexibility (as it is only fused to the full length antibody via one peptide linker) and is quite independent of the linker
20 length.

On the other hand they are suitable for production and pharmaceutical formulation due to their stability, low aggregation and pharmacokinetic and biological properties. Due to their Ig core they still retain the properties of natural antibodies like ADCC and CDC.

25 **Description of the Figures**

Figure 1 Schematic structure of a full length antibody without CH4 domain specifically binding to a first antigen 1 with two pairs of heavy and light chain which comprise variable and constant domains in a typical order.

30 **Figure 2 a - c** Schematic representation of a trivalent, bispecific antibody according to the invention, comprising a full length antibody

(with optional knobs into holes modifications in the CH3 domains) which specifically binds to a first antigen 1 and to whose C-terminus a disulfide-stabilized Fv fragment specifically binding to a second antigen 2, is fused via the N-terminus of either the VH² or the VL² of the disulfide-stabilized Fv fragment

Figure 2 d

Exemplary schematic representation of an intermediate for a bispecific antibody according to the invention as shown in Figure 2a

Figure 3 a -b

Schematic representation of a tetravalent bispecific antibody according to the invention, comprising a full length antibody (with optional knobs into holes modifications in the CH3 domains) which specifically binds to a first antigen 1 and to whose N-terminus a disulfide-stabilized Fv fragment specifically binding to a second antigen 2, is fused via the C-terminus of either the VH² or the VL² of the disulfide-stabilized Fv fragment

Figure 3 c

Exemplary schematic representation of an intermediate for a bispecific antibody according to the invention as shown in Figure 3a

Figure 3 d -e

Schematic representation of a trivalent, bispecific antibody according to the invention, comprising a full length antibody (with optional knobs into holes modifications in the CH3 domains) which specifically binds to a first antigen 1 and to whose N-terminus a disulfide-stabilized Fv fragment specifically binding to a second antigen 2, is fused via the C-terminus of either the VH² or the VL² of the disulfide-stabilized Fv fragment

Figure 4:

Composition of trivalent bispecific antibody derivatives according to the invention

a) Modular composition of trivalent bispecific antibody derivatives according to the invention

b) direct assembly of Fv fragment

c) improved assembly via intermediate with second linker with protease cleavage site, which will be cleaved either during/or after expression to yield the bispecific antibody according to the invention

d) connector-peptides with recognition sequences for proteolytic processing in target cells (by furin) or in vitro (by Prescission protease) for the theintermediate approach under c).

Figure 5: Expression and purification of bispecific dsFv-containing antibody derivatives

(a) Reducing SDS Page of protein preparations after Protein-A and SEC purification

5 **Figure 6:** Reduced binding affinity before protease cleavage:

Reducing SDS-Page of bispecific antibody derivatives before and after protease cleavage.

10 (a) The bispecific antibodies according to the invention containing a Prescission cleavage site are generated with reduced binding affinity and become activated upon exposure to Prescission protease.

15 (b) The bispecific antibodies according to the invention containing a furin cleavage site are generated with reduced binding affinity and become subsequently activated upon exposure to furin.

Figure 7: Binding of restricted and unrestricted trivalent Her3-cMet bispecific antibodies to live cells.

20 Binding of the bivalent unrestricted Her3-modules to Her3-expressing, cMet negative T47D cells is shown in the left panels. Binding of the different restricted cMet-modules to Her3-negative, cMet expressing A549 cells is shown in the right panels. Poor binding is observed for the restricted modules while unleashing by specific proteases leads to full binding and accumulation on cells.

25 **Figure 8:** Inhibitory functionality of trivalent Her3-cMet entities in cellular signaling assays

(a) Western Blot that detects phosphorylated-Her3 demonstrates interference with signaling by the unrestricted Her3-entity.

30 (b) ELISA that detects phosphorylated-ACT demonstrates effective interference with HGF/c-Met signaling by the unrestricted cMet-entity while the same molecule in restricted form has lower activity.

Figure 9: reducing SDS PAGE analysis of Her3-cMet-3C-FS1 displays the presence of the products (52 kD, 12 kD) that were generated by furin processing.

35 **Figure 10** Schematic representation of additional mono- and bispecific antibodies. The lower panel shows abispecific antibodies

according to the invention which bind different target antigens before processing by Furin (left) and after in-process processing by furin (right).

Figure 11: Expression and purification of bispecific furin-processed dsFv-containing antibody derivatives VEGFR_Dig_6C_FS1 and CD22_Dig_6C_FS1. Shown are size exclusion profiles which demonstrate homogeneity and almost complete absence of aggregates in purified protein preparations.

Figure 12: Nonreducing and reducing SDS Page of protein preparations after Protein-A and SEC purification demonstrate homogeneity and correct composition after processing of the purified bispecific antibody derivatives.

Figure 13: Mass spectrometric analyses of protein preparations after Protein-A and SEC purification demonstrate homogeneity and correct composition (complete in-process furin processing) after processing of the purified bispecific antibody derivatives CD22-Dig and VEGFR-Dig.

Figure 14 : Binding analyses by Surface Plasmon Resonance of additional bispecific antibodies according to the invention. Upper panel: For Biacore analyses, bispecific antibodies according to the invention and control antibodies were captured to the chip by anti-Fc antibodies and exposed to soluble forms of the target antigens on cell surfaces (= target 1). On and off rates were calculated from the binding curves by standard techniques. Lower panel: Binding analyses by Surface Plasmon resonance of the LeY-Dig bispecific antibody demonstrates simultaneous binding of target 1 and target 2 specificities. The bispecific antibodies according to the invention were captured to the chip by anti-Fc antibodies, exposed to soluble forms of the target 1 antigen (first binding curve) andf thereafter exposed to target 2 antigen. The appearance of the 2nd antigen derived curve 'on top' of the first binding curve proves that both antigens are bound simultaneously to the bispecific antibody.

Figure 15: Binding analyses by Surface Plasmon Resonance of the additional furin-processed bispecific antibody CD22-Dig according to the invention. Upper panel: For Biacore analyses, bispecific antibodies according to the invention and control

antibodies were captured to the chip by immobilized target 1 antigen CD22 and thereafter exposed to Dig-siRNA as target 2 antigen. On and off rates were calculated from the binding curves by standard techniques. Lower panel: Binding analyses by Surface Plasmon resonance of the CD22-Dig bispecific antibody demonstrates simultaneous binding of target 1 and target 2 specificities. The bispecific antibodies according to the invention were captured to the chip by CD22 binding. The appearance of the 2nd antigen derived curve 'on top' of the first binding curve proves that both antigens are bound simultaneously to the bispecific antibody.

Figure 16: Binding of additional bispecific antibodies according to the invention to live cells. For FACS analyses, bispecific antibodies according to the invention were first incubated with target cells and subsequently incubated with either anti-huCkappa (to detect the bispecific antibody) or to digoxigenated fluorophore (to detect the functionality of the 2nd binding entity). Thereby, binding functionality of both specificities can simultaneously be assessed. Cell associated signals are only detected when bispecifics bind to the cells (functionality towards target 1) and thereafter capture Dig-payload (functionality towards target 2). Bispecifics that do not recognize cell surface targets do not (as expected) generate significant cell associate signals in the same experimental setting.

Detailed Description of the Invention

The current invention relates to a bispecific antibody comprising

- a) a full length antibody specifically binding to a first antigen and consisting of two antibody heavy chains and two antibody light chains;
- b) a Fv fragment specifically binding to a second antigen comprising a VH² domain and a VL² domain, wherein both domains are connected via a disulfide bridge, and

wherein only either the VH² domain or the VL² domain is fused via a peptide linker to the heavy or light chain of the full length antibody specifically binding to a first antigen.

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(and the other of the VH^2 domain or the VL^2 domain is not fused via a peptide linker to the heavy or light chain of the full length antibody specifically binding to a first antigen).

5 In one embodiment the bispecific antibody according to the invention is characterized in that

the VH^2 domain or VL^2 domain is N-terminally fused via a peptide linker to the C-terminus of the heavy or light chain of the full length antibody specifically binding to a first antigen.

10 In one embodiment the bispecific antibody according to the invention is characterized in that

the VH^2 domain is N-terminally fused via a peptide linker to the C-terminus of the heavy or light chain of the full length antibody specifically binding to a first antigen.

15 In one embodiment the bispecific antibody according to the invention is characterized in that

the VH^2 domain is N-terminally fused via a peptide linker to the C-terminus of the heavy chain of the full length antibody specifically binding to a first antigen.

20 In one embodiment the bispecific antibody according to the invention is characterized in that

the VH^2 domain is N-terminally fused via a peptide linker to the C-terminus of the light chain of the full length antibody specifically binding to a first antigen.

25 In one embodiment the bispecific antibody according to the invention is characterized in that

the VL^2 domain is N-terminally fused via a peptide linker to the C-terminus of the heavy or light chain of the full length antibody specifically binding to a first antigen.

30 In one embodiment the bispecific antibody according to the invention is characterized in that

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the VL² domain is N-terminally fused via a peptide linker to the C-terminus of the heavy chain of the full length antibody specifically binding to a first antigen.

5 In one embodiment the bispecific antibody according to the invention is characterized in that

the VL² domain is N-terminally fused via a peptide linker to the C-terminus of the light chain of the full length antibody specifically binding to a first antigen.

10 In one embodiment the bispecific antibody according to the invention is characterized in that

the VH² domain or VL² domain is N-terminally fused via a peptide linker to the C-terminus of the heavy or light chain of the full length antibody specifically binding to a first antigen; and

15 a CH1 domain is N-terminally fused to the the C-terminus VH² domain and a CL domain is N-terminally fused to the the C-terminus VL² domain (see e.g. Fig 2c).

In one embodiment the bispecific antibody according to the invention is characterized in that

20 the VH² domain or VL² domain is C-terminally fused via a peptide linker to the N-terminus of the heavy or light chain of the full length antibody specifically binding to a first antigen.

In one embodiment the bispecific antibody according to the invention is characterized in that

25 the VH² domain is C-terminally fused via a peptide linker to the N-terminus of the heavy or light chain of the full length antibody specifically binding to a first antigen,

In one embodiment the bispecific antibody according to the invention is characterized in that

the VH² domain is C-terminally fused via a peptide linker to the N-terminus of the heavy chain of the full length antibody specifically binding to a first antigen.

5 In one embodiment the bispecific antibody according to the invention is characterized in that

the VH² domain is C-terminally fused via a peptide linker to the N-terminus of the light chain of the full length antibody specifically binding to a first antigen.

10 In one embodiment the bispecific antibody according to the invention is characterized in that

the VL² domain is C-terminally fused via a peptide linker to the N-terminus of the heavy or light chain of the full length antibody specifically binding to a first antigen.

15 In one embodiment the bispecific antibody according to the invention is characterized in that

the VL² domain is C-terminally fused via a peptide linker to the N-terminus of the heavy chain of the full length antibody specifically binding to a first antigen.

20 In one embodiment the bispecific antibody according to the invention is characterized in that

the VL² domain is C-terminally fused via a peptide linker to the N-terminus of the light chain of the full length antibody specifically binding to a first antigen.

25 In one embodiment the bispecific antibody according to the invention is characterized in that

a) the bispecific antibody is trivalent and

b) either the VH² domain or the VL² domain is fused via a peptide linker to the heavy chain of the full length antibody specifically binding to a first antigen.

In one embodiment such trivalent, bispecific antibody is characterized in that the VH^2 domain or VL^2 domain is N-terminally fused via a peptide linker to the C-terminus of the heavy chain of the full length antibody specifically binding to a first antigen.

5 In one embodiment such trivalent bispecific antibody is characterized in that the VH^2 domain or VL^2 domain is C-terminally fused via a peptide linker to the N-terminus of the heavy chain of the full length antibody specifically binding to a first antigen.

10 In one embodiment the bispecific antibody according to the invention is characterized in that

the VH^2 domain and the VL^2 domain are connected via a disulfide bridge which is introduced between the following positions:

- 15 i) VH^2 domain position 44 and VL^2 domain position 100,
ii) VH^2 domain position 105 and VL^2 domain position 43, or
iii) VH^2 domain position 101 and VL^2 domain position 100
(numbering always according to EU index of Kabat).

In one embodiment the bispecific antibody according to the invention is characterized in that

20 the VH^2 domain and the VL^2 domain are connected via a disulfide bridge which is introduced between VH^2 domain position 44 and VL^2 domain position 100 (numbering always according to EU index of Kabat).

25 Techniques to introduce unnatural disulfide bridges for stabilization are described e.g. in WO 94/029350, US 5,747,654, Rajagopal, V., et al., Prot. Engin. 10 (1997) 1453-1459; Reiter, Y., et al., Nature Biotechnology 14 (1996) 1239-1245; Reiter, Y., et al., Protein Engineering; 8 (1995) 1323-1331; Webber, K.O., et al., Molecular Immunology 32 (1995) 249-258; Reiter, Y., et al., Immunity 2 (1995) 281-287; Reiter, Y., et al., JBC 269 (1994) 18327-18331; Reiter, Y., et al., Inter. J. of Cancer 58 (1994) 142-149, or Reiter, Y., Cancer Res. 54 (1994) 2714-2718. In
30 one embodiment the optional disulfide bond between the variable domains of the polypeptides under b) and c) is between heavy chain variable domain position 44 and light chain variable domain position 100. In one embodiment the optional disulfide bond between the variable domains of the polypeptides under b) and c) is

between heavy chain variable domain position 105 and light chain variable domain position 43 (numbering always according to EU index of Kabat). In one embodiment a trivalent, bispecific antibody without said optional disulfide stabilization between the variable domains VH and VL of the single chain Fab fragments is preferred.

The term “full length antibody” denotes an antibody consisting of two “full length antibody heavy chains” and two “full length antibody light chains” (see Fig. 1). A “full length antibody heavy chain” is a polypeptide consisting in N-terminal to C-terminal direction of an antibody heavy chain variable domain (VH), an antibody constant heavy chain domain 1 (CH1), an antibody hinge region (HR), an antibody heavy chain constant domain 2 (CH2), and an antibody heavy chain constant domain 3 (CH3), abbreviated as VH-CH1-HR-CH2-CH3; and optionally an antibody heavy chain constant domain 4 (CH4) in case of an antibody of the subclass IgE. Preferably the “full length antibody heavy chain” is a polypeptide consisting in N-terminal to C-terminal direction of VH, CH1, HR, CH2 and CH3. A “full length antibody light chain” is a polypeptide consisting in N-terminal to C-terminal direction of an antibody light chain variable domain (VL), and an antibody light chain constant domain (CL), abbreviated as VL-CL. The antibody light chain constant domain (CL) can be κ (kappa) or λ (lambda). The two full length antibody chains are linked together via inter-polypeptide disulfide bonds between the CL domain and the CH1 domain and between the hinge regions of the full length antibody heavy chains. Examples of typical full length antibodies are natural antibodies like IgG (e.g. IgG 1 and IgG2), IgM, IgA, IgD, and IgE.) The full length antibodies according to the invention can be from a single species e.g. human, or they can be chimerized or humanized antibodies. The full length antibodies according to the invention comprise two antigen binding sites each formed by a pair of VH and VL, which both specifically bind to the same antigen. The C-terminus of the heavy or light chain of said full length antibody denotes the last amino acid at the C-terminus of said heavy or light chain.

The N-terminus of the antibody heavy chain variable domain (VH) of the polypeptide under b) and the antibody light chain variable domain (VL) of the polypeptide under c) denotes the last amino acid at the N- terminus of VH or VL domain.

The term “Fv fragment” as used herein refers to a VH² domain and a VL² domain of an antibody specifically binding to an antigen, both domains forming together a

Fv fragment. The Fv fragment binding to the second antigen within the bispecific antibody according to the invention comprises a (interchain) disulfide bridge between both domains VH^2 and VL^2 , i.e. the domains VH^2 domain and a VL^2 both are connected via a unnatural disulfide bridge for stabilization, which is introduced by techniques described e.g. in WO 94/029350, US 5,747,654, Rajagopal, V., et al., Prot. Engin. 10 (1997) 1453-1459; Reiter, Y., et al., Nature Biotechnology 14 (1996) 1239-1245; Reiter, Y., et al., Protein Engineering; 8 (1995) 1323-1331; Webber, K.O., et al., Molecular Immunology 32 (1995) 249-258; Reiter, Y., et al., Immunity 2 (1995) 281-287; Reiter, Y., et al., JBC 269 (1994) 18327-18331; Reiter, Y., et al., Inter. J. of Cancer 58 (1994) 142-149, or Reiter, Y., Cancer Res. 54 (1994) 2714-2718.

The VH^2 and VL^2 domains of the Fv fragment binding to the second antigen within the bispecific antibody according to the invention are not connected via a peptide linker with each other (i.e. VH^2 and VL^2 do not form a single chain Fv fragments). Therefore the term “a Fv fragment specifically binding to a second antigen comprising a VH^2 domain and a VL^2 domain, wherein both domains are connected via a disulfide bridge” refers a Fv fragment to a wherein both domains are connected via a disulfide bridge as only covalent linkage between both domains” and not to via a further covalent linkage (as for example in a single chain Fv fragments via a peptide linker).

The domains VH^2 and VL^2 of the Fv fragment can either be derived from a full length antibody or other techniques like e.g. phage display.

In one embodiment the bispecific antibody according to the invention is a trivalent, bispecific antibody and the Fv fragment (binding to a second antigen) is fused to the heavy chain of the full length antibody binding to the first antigen. The term “valent” as used within the current application denotes the presence of a specified number of binding sites in an antibody molecule. A natural antibody for example or a full length antibody according to the invention has two binding sites and is bivalent. As such, the term “trivalent”, denote the presence of three binding sites in an antibody molecule. The term “trivalent, trispecific” antibody as used herein denotes an antibody that has three antigen-binding sites of which each binds to another antigen (or another epitope of the antigen). Antibodies of the present invention have three to four binding sites, i.e. are tri- or tetravalent (preferably tri valent) and are bispecific.

Antibody specificity refers to selective recognition of the antibody for a particular epitope of an antigen. Natural antibodies, for example, are monospecific. Bispecific antibodies are antibodies which have two different antigen-binding specificities. Where an antibody has more than one specificity, the recognized epitopes may be associated with a single antigen or with more than one antigen.

The term “monospecific” antibody as used herein denotes an antibody that has one or more binding sites each of which bind to the same epitope of the same antigen.

Typical trivalent, bispecific antibodies according to the invention are shown e.g in Figure 2a and 2b, 3d and 3c.

For a trivalent, bispecific antibodies according to the invention modifications in the CH3 domain enhancing the the heterodimerization of the two different heavy chains (see Figures Figure 2a and 2b, 3d and 3c) are especially useful.

Therefore for such trivalent, bispecific antibodies the CH3 domains of said full length antibody according to the invention can be altered by the “knob-into-holes” technology which is described in detail with several examples in e.g. WO 96/027011, Ridgway, J.B., et al., Protein Eng 9 (1996) 617-621; and Merchant, A.M., et al., Nat Biotechnol 16 (1998) 677-681. In this method the interaction surfaces of the two CH3 domains are altered to increase the heterodimerisation of both heavy chains containing these two CH3 domains. Each of the two CH3 domains (of the two heavy chains) can be the “knob”, while the other is the “hole”. The introduction of a disulfide bridge further stabilizes the heterodimers (Merchant, A.M., et al., Nature Biotech 16 (1998) 677-681; Atwell, S., et al., J. Mol. Biol. 270 (1997) 26-35) and increases the yield.

Thus in one aspect of the invention said trivalent, bispecific antibody is further is characterized in that

the CH3 domain of one heavy chain of the full length antibody and the CH3 domain of the other heavy chain of the full length antibody each meet at an interface which comprises an original interface between the antibody CH3 domains;

wherein said interface is altered to promote the formation of the bivalent, bispecific antibody, wherein the alteration is characterized in that:

a) the CH3 domain of one heavy chain is altered,

so that within the original interface the CH3 domain of one heavy chain that meets the original interface of the CH3 domain of the other heavy chain within the bivalent, bispecific antibody,

an amino acid residue is replaced with an amino acid residue having a larger side chain volume, thereby generating a protuberance within the interface of the CH3 domain of one heavy chain which is positionable in a cavity within the interface of the CH3 domain of the other heavy chain

and

b) the CH3 domain of the other heavy chain is altered,

so that within the original interface of the second CH3 domain that meets the original interface of the first CH3 domain within the trivalent, bispecific antibody an amino acid residue is replaced with an amino acid residue having a smaller side chain volume, thereby generating a cavity within the interface of the second CH3 domain within which a protuberance within the interface of the first CH3 domain is positionable.

Preferably said amino acid residue having a larger side chain volume is selected from the group consisting of arginine (R), phenylalanine (F), tyrosine (Y), tryptophan (W).

Preferably said amino acid residue having a smaller side chain volume is selected from the group consisting of alanine (A), serine (S), threonine (T), valine (V).

In one aspect of the invention both CH3 domains are further altered by the introduction of cysteine (C) as amino acid in the corresponding positions of each CH3 domain such that a disulfide bridge between both CH3 domains can be formed.

In a preferred embodiment, said trivalent, bispecific comprises a T366W mutation in the CH3 domain of the "knobs chain" and T366S, L368A, Y407V mutations in the CH3 domain of the "hole chain". An additional interchain disulfide bridge between the CH3 domains can also be used (Merchant, A.M., et al., Nature Biotech 16 (1998) 677-681) e.g. by introducing a Y349C mutation into the CH3 domain of the "knobs chain" and a E356C mutation or a S354C mutation into the CH3 domain of the "hole chain". Thus in a another preferred embodiment, said trivalent, bispecific antibody comprises Y349C, T366W mutations in one of the two CH3 domains and E356C, T366S, L368A, Y407V mutations in the other of the two CH3 domains or said trivalent, bispecific antibody comprises Y349C, T366W mutations in one of the two CH3 domains and S354C, T366S, L368A, Y407V mutations in the other of the two CH3 domains (the additional Y349C mutation in one CH3

domain and the additional E356C or S354C mutation in the other CH3 domain forming a interchain disulfide bridge) (numbering always according to EU index of Kabat). But also other knobs-in-holes technologies as described by EP 1 870 459A1, can be used alternatively or additionally. A preferred example for said trivalent, bispecific antibody are R409D; K370E mutations in the CH3 domain of the “knobs chain” and D399K; E357K mutations in the CH3 domain of the “hole chain” (numbering always according to EU index of Kabat).

In another preferred embodiment said trivalent, bispecific antibody comprises a T366W mutation in the CH3 domain of the “knobs chain” and T366S, L368A, Y407V mutations in the CH3 domain of the “hole chain” and additionally R409D; K370E mutations in the CH3 domain of the “knobs chain” and D399K; E357K mutations in the CH3 domain of the “hole chain”.

In another preferred embodiment said trivalent, bispecific antibody comprises Y349C, T366W mutations in one of the two CH3 domains and S354C, T366S, L368A, Y407V mutations in the other of the two CH3 domains or said trivalent, bispecific antibody comprises Y349C, T366W mutations in one of the two CH3 domains and S354C, T366S, L368A, Y407V mutations in the other of the two CH3 domains and additionally R409D; K370E mutations in the CH3 domain of the “knobs chain” and D399K; E357K mutations in the CH3 domain of the “hole chain”.

The bispecific antibody to the invention comprises different antigen-binding sites. The full length antibody according comprises two identical antigen-binding sites specifically binding to a first antigen, and the antibody heavy chain variable domain VH^2 the antibody light chain variable domain VL^2 of the disulfide stabilized Fv fragment form together one antigen binding site specifically binding to a second antigen.

The terms “binding site” or “antigen-binding site” as used herein denotes the region(s) of said bispecific antibody according to the invention to which the respective antigen actually specifically binds. The antigen binding sites either in the full length antibody or in the Fv fragment are formed each by a pair consisting of an antibody light chain variable domain (VL) and an antibody heavy chain variable domain (VH).

The antigen-binding sites that specifically bind to the desired antigen can be derived a) from known antibodies to the antigen or b) from new antibodies or

antibody fragments obtained by de novo immunization methods using inter alia either the antigen protein or nucleic acid or fragments thereof or by phage display.

5 An antigen-binding site of an antibody of the invention contains six complementarity determining regions (CDRs) which contribute in varying degrees to the affinity of the binding site for antigen. There are three heavy chain variable domain CDRs (CDRH1, CDRH2 and CDRH3) and three light chain variable domain CDRs (CDRL1, CDRL2 and CDRL3). The extent of CDR and framework regions (FRs) is determined by comparison to a compiled database of amino acid sequences in which those regions have been defined according to variability among
10 the sequences.

Antibody specificity refers to selective recognition of the antibody for a particular epitope of an antigen. Natural antibodies, for example, are monospecific. "Bispecific antibodies" according to the invention are antibodies which have two different antigen-binding specificities. Where an antibody has more than one
15 specificity, the recognized epitopes may be associated with a single antigen or with more than one antigen. The term "monospecific" antibody as used herein denotes an antibody that has one or more binding sites each of which bind to the same epitope of the same antigen.

The term "valent" as used within the current application denotes the presence of a specified number of binding sites in an antibody molecule. A natural antibody for
20 example or a full length antibody according to the invention has two binding sites and is bivalent. As such, the terms "trivalent", denote the presence of three binding sites in an antibody molecule. As such, the terms "tetravalent", denote the presence of three binding sites in an antibody molecule. In one embodiment the bispecific antibodies according to the invention are trivalent or tetravalent. In one
25 embodiment the bispecific antibodies according to the invention are trivalent.

The full length antibodies of the invention comprise immunoglobulin constant regions of one or more immunoglobulin classes. Immunoglobulin classes include IgG, IgM, IgA, IgD, and IgE isotypes and, in the case of IgG and IgA, their
30 subtypes. In a preferred embodiment, an full length antibody of the invention has a constant domain structure of an IgG type antibody.

The terms "monoclonal antibody" or "monoclonal antibody composition" as used herein refer to a preparation of antibody molecules of a single amino acid composition.

The term "chimeric antibody" refers to an antibody comprising a variable region, i.e., binding region, from one source or species and at least a portion of a constant region derived from a different source or species, usually prepared by recombinant DNA techniques. Chimeric antibodies comprising a murine variable region and a human constant region are preferred. Other preferred forms of "chimeric antibodies" encompassed by the present invention are those in which the constant region has been modified or changed from that of the original antibody to generate the properties according to the invention, especially in regard to C1q binding and/or Fc receptor (FcR) binding. Such chimeric antibodies are also referred to as "class-switched antibodies.". Chimeric antibodies are the product of expressed immunoglobulin genes comprising DNA segments encoding immunoglobulin variable regions and DNA segments encoding immunoglobulin constant regions. Methods for producing chimeric antibodies involve conventional recombinant DNA and gene transfection techniques are well known in the art. See, e.g., Morrison, S.L., et al., Proc. Natl. Acad. Sci. USA 81 (1984) 6851-6855; US 5,202,238 and US 5,204,244.

The term "humanized antibody" refers to antibodies in which the framework or "complementarity determining regions" (CDR) have been modified to comprise the CDR of an immunoglobulin of different specificity as compared to that of the parent immunoglobulin. In a preferred embodiment, a murine CDR is grafted into the framework region of a human antibody to prepare the "humanized antibody". See, e.g., Riechmann, L., et al., Nature 332 (1988) 323-327; and Neuberger, M.S., et al., Nature 314 (1985) 268-270. Particularly preferred CDRs correspond to those representing sequences recognizing the antigens noted above for chimeric antibodies. Other forms of "humanized antibodies" encompassed by the present invention are those in which the constant region has been additionally modified or changed from that of the original antibody to generate the properties according to the invention, especially in regard to C1q binding and/or Fc receptor (FcR) binding.

The term "human antibody", as used herein, is intended to include antibodies having variable and constant regions derived from human germ line immunoglobulin sequences. Human antibodies are well-known in the state of the art (van Dijk, M.A., and van de Winkel, J.G., Curr. Opin. Chem. Biol. 5 (2001) 368-374). Human antibodies can also be produced in transgenic animals (e.g., mice) that are capable, upon immunization, of producing a full repertoire or a selection of human antibodies in the absence of endogenous immunoglobulin

production. Transfer of the human germ-line immunoglobulin gene array in such germ-line mutant mice will result in the production of human antibodies upon antigen challenge (see, e.g., Jakobovits, A., et al., Proc. Natl. Acad. Sci. USA 90 (1993) 2551-2555; Jakobovits, A., et al., Nature 362 (1993) 255-258; Brüggemann, M., et al., Year Immunol. 7 (1993) 33-40). Human antibodies can also be produced in phage display libraries (Hoogenboom, H.R., and Winter, G.J., Mol. Biol. 227 (1992) 381-388; Marks, J.D., et al., J. Mol. Biol. 222 (1991) 581-597). The techniques of Cole, S.P.C., et al., and Boerner, P., et al., are also available for the preparation of human monoclonal antibodies (Cole, S.P.C., et al., Monoclonal Antibodies and Cancer Therapy, Alan R. Liss, (1985) 77-96); and Boerner, P., et al., J. Immunol. 147 (1991) 86-95). As already mentioned for chimeric and humanized antibodies according to the invention the term "human antibody" as used herein also comprises such antibodies which are modified in the constant region to generate the properties according to the invention, especially in regard to C1q binding and/or FcR binding, e.g. by "class switching" i.e. change or mutation of Fc parts (e.g. from IgG1 to IgG4 and/or IgG1/IgG4 mutation).

The term "recombinant human antibody", as used herein, is intended to include all human antibodies that are prepared, expressed, created or isolated by recombinant means, such as antibodies isolated from a host cell such as a HEK293 cells, and CHO or CHO cell or from an animal (e.g. a mouse) that is transgenic for human immunoglobulin genes or antibodies expressed using a recombinant expression vector transfected into a host cell. Such recombinant human antibodies have variable and constant regions in a rearranged form. The recombinant human antibodies according to the invention have been subjected to in vivo somatic hypermutation. Thus, the amino acid sequences of the VH and VL regions of the recombinant antibodies are sequences that, while derived from and related to human germ line VH and VL sequences, may not naturally exist within the human antibody germ line repertoire in vivo.

The "variable domain" (variable domain of a light chain (VL), variable region of a heavy chain (VH) as used herein denotes each of the pair of light and heavy chains which is involved directly in binding the antibody to the antigen. The domains of variable human light and heavy chains have the same general structure and each domain comprises four framework (FR) regions whose sequences are widely conserved, connected by three "hypervariable regions" (or complementarity determining regions, CDRs). The framework regions adopt a β -sheet conformation and the CDRs may form loops connecting the β -sheet structure. The CDRs in each

chain are held in their three-dimensional structure by the framework regions and form together with the CDRs from the other chain the antigen binding site. The antibody heavy and light chain CDR3 regions play a particularly important role in the binding specificity/affinity of the antibodies according to the invention and therefore provide a further object of the invention.

The terms "hypervariable region" or "antigen-binding portion of an antibody" when used herein refer to the amino acid residues of an antibody which are responsible for antigen-binding. The hypervariable region comprises amino acid residues from the "complementarity determining regions" or "CDRs". "Framework" or "FR" regions are those variable domain regions other than the hypervariable region residues as herein defined. Therefore, the light and heavy chains of an antibody comprise from N- to C-terminus the domains FR1, CDR1, FR2, CDR2, FR3, CDR3, and FR4. CDRs on each chain are separated by such framework amino acids. Especially, CDR3 of the heavy chain is the region which contributes most to antigen binding. CDR and FR regions are determined according to the standard definition of Kabat, E.A., et al., Sequences of Proteins of Immunological Interest, 5th ed., Public Health Service, National Institutes of Health, Bethesda, MD (1991).

As used herein, the term "binding" or "specifically binding" refers to the binding of the antibody to an epitope of the antigen in an in vitro assay, preferably in an plasmon resonance assay (BIAcore, GE-Healthcare Uppsala, Sweden) with purified wild-type antigen. The affinity of the binding is defined by the terms k_a (rate constant for the association of the antibody from the antibody/antigen complex), k_D (dissociation constant), and K_D (k_D/k_a). Binding or specifically binding means a binding affinity (K_D) of 10^{-8} M or less, e.g. 10^{-8} M to 10^{-13} M, preferably 10^{-9} M to 10^{-13} M. Thus, an bispecific antibody according to the invention is specifically binding to each antigen for which it is specific with a binding affinity (K_D) of 10^{-8} M or less, e.g. 10^{-8} M to 10^{-13} M, preferably 10^{-9} M to 10^{-13} M.

The term "epitope" includes any polypeptide determinant capable of specific binding to an antibody. In certain embodiments, epitope determinant include chemically active surface groupings of molecules such as amino acids, sugar side chains, phosphoryl, or sulfonyl, and, in certain embodiments, may have specific three dimensional structural characteristics, and or specific charge characteristics. An epitope is a region of an antigen that is bound by an antibody.

In certain embodiments, an antibody is said to specifically bind an antigen when it preferentially recognizes its target antigen in a complex mixture of proteins and/or macromolecules.

5 The term “peptide linker” as used herein for final the antibody according to the invention denotes a peptide with amino acid sequences, which is preferably of synthetic origin. These peptide connectors according to invention are used to fuse the disulfide stabilized Fv fragment binding to the second antigen to the to the heavy chain C- or N-termini of the full length antibody to form the bispecific antibody according to the invention. Preferably said peptide linkers are peptides
10 with an amino acid sequence with a length of at least 5 amino acids, preferably with a length of 10 to 100 amino acids, more preferably with a length of 25 to 50 amino acids. In one embodiment said peptide linker is e.g. (GxS)_n or (GxS)_nG_m with G = glycine, S = serine, and (x = 3, n = 3, 4, 5 or 6, and m = 0, 1, 2 or 3) or (x = 4, n = 2, 3, 4, 5 or 6, and m = 0, 1, 2 or 3), preferably x = 4 and n = 2, 3, 4, 5
15 or 6, and m = 0. In one embodiment “peptide linker” as used within the antibody according to the invention does not comprise a protease cleavage site. Each terminus of the peptide linker is conjugated to one polypeptide chain (e.g. a VH domain, a VL domain, an antibody heavy chain, an antibody light chain, a CH1-VH chain, etc.).

20 The term “peptide linker” as used for the intermediate antibody as described below (which is processed to the antibody according to the invention either during expression or after expression) denotes a peptide with amino acid sequences, which is e.g. of synthetic origin. Preferably said peptide linkers under are peptides with an amino acid sequence with a length of at least 5 amino acids, preferably with a
25 length of 5 to 100, more preferably of 10 to 50 amino acids. Each terminus of the peptide linker is conjugated to one polypeptide chain (e.g. a VH domain, a VL domain, an antibody heavy chain, an antibody light chain, a CH1-VH chain, etc.).

One of the peptide linkers within the intermediate bispecific antibody a does not comprise a protease cleavage site and is identical to the peptide linker of the final
30 bispecific antibody according to the invention as described above. In one embodiment said peptide linker without a protease cleavage site is e.g. (GxS)_n or (GxS)_nG_m with G = glycine, S = serine, and (x = 3, n = 3, 4, 5 or 6, and m = 0, 1, 2 or 3) or (x = 4, n = 2, 3, 4, 5 or 6, and m = 0, 1, 2 or 3), preferably x = 4 and n = 2, 3, 4, 5 or 6, and m = 0.

The other peptide linker of the intermediate antibody as described below comprises a protease cleavage site, which is cleavable either during expression (e.g. by furin) or after expression (/and purification) e.g.. In general a protease cleavage site within a peptide linker is an amino acid sequence or motif which is cleaved by a protease. Natural or artificial protease cleavage sites for different proteases are described e.g. in Database, Vol. 2009, Article ID bap015, doi:10.1093/database/bap015 and the referred MEROPS peptide database (<http://merops.sanger.ac.uk/>). Furin specific protease cleavage sites are e.g. QSSRHRRAL (Furin specific protease cleavage site variant 1 - FS1 of SEQ ID NO. 13), OR LSHRSKRSL (Furin specific protease cleavage site variant 2 – FS2 of SEQ ID NO. 14). PreScission specific protease cleavage sites are e.g. QSSRHRRAL (PreScission specific protease cleavage site of SEQ ID NO. 15) LEVLFQGP.

Furin is a protein that in humans is encoded by the *FURIN* gene and belongs to the endo peptidases (Endopeptidases: serine proteases/serine endopeptidases (EC 3.4.21)). It was named furin because it was in the upstream region of an oncogene known as FES. The gene was known as FUR (FES Upstream Region) and therefore the protein was named furin. Furin is also known as PACE (Paired basic Amino Cleaving Enzyme). The protein encoded by this gene is an enzyme which belongs to the subtilisin-like proprotein convertase family. The members of this family are proprotein convertases that process latent precursor proteins into their biologically active products. This encoded protein is a calcium-dependent serine endoprotease that can efficiently cleave precursor proteins at their paired basic amino acid processing sites. Some of its substrates are: parathyroid hormone, transforming growth factor beta 1 precursor, proalbumin, pro-beta-secretase, membrane type-1 matrix metalloproteinase, beta subunit of pro-nerve growth factor and von Willebrand factor. A furin-like pro-protein convertase has been implicated in the processing of RGMc (also called hemojuvelin Hemojuvelin), a gene involved in a severe iron-overload disorder called juvenile hemochromatosis. Both the Ganz and Rotwein groups demonstrated that furin-like proprotein convertases (PPC) are responsible for conversion of 50 kDa HJV to a 40 kDa protein with a truncated COOH-terminus, at a conserved polybasic RNRR site. This suggests a potential mechanism to generate the soluble forms of HJV/hemojuvelin (s-hemojuvelin) found in the blood of rodents and humans. Furin is present in endocytic and secretory vesicles, in the trans-Golgi network and in some cases on cell surfaces of many mammalian cells (e.g HEK293, CHO). Its recognition sites frequently contain the motif RXK/RR which are present in a variety of secreted

precursor proteins such as pro-TGF β 1 or pro-van Willebrand factor. Therefore, we selected these recognition sequences for generating two furin site containing connector sequences (Furin specific protease cleavage site variant 1 - FS1 of SEQ ID NO:13 and Furin specific protease cleavage site variant 2 – FS2 of SEQ ID NO:14.

PreScission Protease (GE Healthcare Catalogue No. 27-0843-01) is a genetically engineered fusion protein consisting of human rhinovirus 3C protease and GST. This protease was specifically designed to facilitate removal of the protease by allowing simultaneous protease immobilization and cleavage of GST fusion proteins produced from the pGEX-6P vectors pGEX-6P-1, pGEX-6P-2, and pGEX-6P-3; see pGEX Vectors (GST Gene Fusion System). PreScission Protease specifically cleaves between the Gln and Gly residues of the recognition sequence of LeuGluValLeuPheGln/GlyPro (Walker, P.A., et al., BIO/TECHNOLOGY 12, (1994) 601-605; Cordingley, M.G., et al., J. Biol. Chem. 265 (1990) 9062-9065).

The bispecific antibodies according to the invention have valuable characteristics such as biological or pharmacological activity, pharmacokinetic properties. They can be used e.g. for the treatment of diseases such as cancer.

In a further embodiment the bispecific antibody according to the invention is characterized in specifically binding to ErbB3 and c-Met.

The term “constant region” as used within the current applications denotes the sum of the domains of an antibody other than the variable region. The constant region is not involved directly in binding of an antigen, but exhibit various effector functions. Depending on the amino acid sequence of the constant region of their heavy chains, antibodies are divided in the classes: IgA, IgD, IgE, IgG and IgM, and several of these may be further divided into subclasses, such as IgG1, IgG2, IgG3, and IgG4, IgA1 and IgA2. The heavy chain constant regions that correspond to the different classes of antibodies are called α , δ , ϵ , γ , and μ , respectively. The light chain constant regions (CL) which can be found in all five antibody classes are called κ (kappa) and λ (lambda).

The term “constant region derived from human origin” as used in the current application denotes a constant heavy chain region of a human antibody of the subclass IgG1, IgG2, IgG3, or IgG4 and/or a constant light chain kappa or lambda region. Such constant regions are well known in the state of the art and e.g. described by Kabat, E.A., (see e.g. Johnson, G., and Wu, T.T., Nucleic Acids Res.

28 (2000) 214-218; Kabat, E.A., et al., Proc. Natl. Acad. Sci. USA 72 (1975) 2785-2788).

While antibodies of the IgG4 subclass show reduced Fc receptor (FcγRIIIa) binding, antibodies of other IgG subclasses show strong binding. However Pro238, Asp265, Asp270, Asn297 (loss of Fc carbohydrate), Pro329, Leu234, Leu235, Gly236, Gly237, Ile253, Ser254, Lys288, Thr307, Gln311, Asn434, and His435 are residues which, if altered, provide also reduced Fc receptor binding (Shields, R.L., et al., J. Biol. Chem. 276 (2001) 6591-6604; Lund, J., et al., FASEB J. 9 (1995) 115-119; Morgan, A., et al., Immunology 86 (1995) 319-324; EP 0 307 434).

In one embodiment an antibody according to the invention has a reduced FcR binding compared to an IgG1 antibody and the full length parent antibody is in regard to FcR binding of IgG4 subclass or of IgG1 or IgG2 subclass with a mutation in S228, L234, L235 and/or D265, and/ or contains the PVA236 mutation. In one embodiment the mutations in the full length parent antibody are S228P, L234A, L235A, L235E and/or PVA236. In another embodiment the mutations in the full length parent antibody are in IgG4 S228P and in IgG1 L234A and L235A.

The constant region of an antibody is directly involved in ADCC (antibody-dependent cell-mediated cytotoxicity) and CDC (complement-dependent cytotoxicity). Complement activation (CDC) is initiated by binding of complement factor C1q to the constant region of most IgG antibody subclasses. Binding of C1q to an antibody is caused by defined protein-protein interactions at the so called binding site. Such constant region binding sites are known in the state of the art and described e.g. by Lukas, T.J., et al., J. Immunol. 127 (1981) 2555-2560; Brunhouse, R. and Cebra, J.J., Mol. Immunol. 16 (1979) 907-917; Burton, D.R., et al., Nature 288 (1980) 338-344; Thommesen, J.E., et al., Mol. Immunol. 37 (2000) 995-1004; Idusogie, E.E., et al., J. Immunol. 164 (2000) 4178-4184; Hezareh, M., et al., J. Virol. 75 (2001) 12161-12168; Morgan, A., et al., Immunology 86 (1995) 319-324; and EP 0 307 434. Such constant region binding sites are, e.g., characterized by the amino acids L234, L235, D270, N297, E318, K320, K322, P331, and P329 (numbering according to EU index of Kabat).

The term “antibody-dependent cellular cytotoxicity (ADCC)” refers to lysis of human target cells by an antibody according to the invention in the presence of effector cells. ADCC is measured preferably by the treatment of a preparation of antigen expressing cells with an antibody according to the invention in the presence

of effector cells such as freshly isolated PBMC or purified effector cells from buffy coats, like monocytes or natural killer (NK) cells or a permanently growing NK cell line.

5 The term “complement-dependent cytotoxicity (CDC)” denotes a process initiated by binding of complement factor C1q to the Fc part of most IgG antibody subclasses. Binding of C1q to an antibody is caused by defined protein-protein interactions at the so called binding site. Such Fc part binding sites are known in the state of the art (see above). Such Fc part binding sites are, e.g., characterized by the amino acids L234, L235, D270, N297, E318, K320, K322, P331, and P329
10 (numbering according to EU index of Kabat). Antibodies of subclass IgG1, IgG2, and IgG3 usually show complement activation including C1q and C3 binding, whereas IgG4 does not activate the complement system and does not bind C1q and/or C3.

Cell-mediated effector functions of monoclonal antibodies can be enhanced by
15 engineering their oligosaccharide component as described in Umana, P., et al., Nature Biotechnol. 17 (1999) 176-180, and US 6,602,684. IgG1 type antibodies, the most commonly used therapeutic antibodies, are glycoproteins that have a conserved N-linked glycosylation site at Asn297 in each CH2 domain. The two complex biantennary oligosaccharides attached to Asn297 are buried between the
20 CH2 domains, forming extensive contacts with the polypeptide backbone, and their presence is essential for the antibody to mediate effector functions such as antibody dependent cellular cytotoxicity (ADCC) (Lifely, M.R., et al., Glycobiology 5 (1995) 813-822; Jefferis, R., et al., Immunol. Rev. 163 (1998) 59-76; Wright, A., and Morrison, S.L., Trends Biotechnol. 15 (1997) 26-32). Umana, P., et al. Nature
25 Biotechnol. 17 (1999) 176-180 and WO 99/154342 showed that overexpression in Chinese hamster ovary (CHO) cells of β (1,4)-N-acetylglucosaminyltransferase III (“GnTIII”), a glycosyltransferase catalyzing the formation of bisected oligosaccharides, significantly increases the in vitro ADCC activity of antibodies. Alterations in the composition of the Asn297 carbohydrate or its elimination affect
30 also binding to Fc γ R and C1q (Umana, P., et al., Nature Biotechnol. 17 (1999) 176-180; Davies, J., et al., Biotechnol. Bioeng. 74 (2001) 288-294; Mimura, Y., et al., J. Biol. Chem. 276 (2001) 45539-45547; Radaev, S., et al., J. Biol. Chem. 276 (2001) 16478-16483; Shields, R.L., et al., J. Biol. Chem. 276 (2001) 6591-6604; Shields, R.L., et al., J. Biol. Chem. 277 (2002) 26733-26740; Simmons, L.C., et al., J.
35 Immunol. Methods 263 (2002) 133-147).

Methods to enhance cell-mediated effector functions of monoclonal antibodies are reported e.g. in WO 2005/044859, WO 2004/065540, WO2007/031875, Umana, P., et al., Nature Biotechnol. 17 (1999) 176-180, WO 99/154342, WO 2005/018572, WO 2006/116260, WO 2006/114700, WO 2004/065540, 5 WO 2005/011735, WO 2005/027966, WO 1997/028267, US 2006/0134709, US 2005/0054048, US 2005/0152894, WO 2003/035835 and WO 2000/061739 or e.g. in Niwa, R., et al., J. Immunol. Methods 306 (2005) 151-160; Shinkawa, T., et al., J. Biol. Chem. 278 (2003) 3466-3473; WO 03/055993 and US 2005/0249722.

10 In one embodiment of the invention, the bispecific antibody is glycosylated (if it comprises an Fc part of IgG1, IgG2, IgG3 or IgG4 subclass, preferably of IgG1 or IgG3 subclass) with a sugar chain at Asn297 whereby the amount of fucose within said sugar chain is 65 % or lower (Numbering according to Kabat). In another embodiment is the amount of fucose within said sugar chain is between 5 % and 65 %, preferably between 20 % and 40 %. In an alternative embodiment, the 15 amount of fucose is 0% of the oligosaccharides of the Fc region at Asn297. "Asn297" according to the invention means amino acid asparagine located at about position 297 in the Fc region. Based on minor sequence variations of antibodies, Asn297 can also be located some amino acids (usually not more than ± 3 amino acids) upstream or downstream of position 297, i.e. between position 294 and 300. 20 In one embodiment the glycosylated antibody according to the invention the IgG subclass is of human IgG1 subclass, of human IgG1 subclass with the mutations L234A and L235A or of IgG3 subclass. In a further embodiment the amount of N-glycolylneuraminic acid (NGNA) is 1 % or less and/or the amount of N-terminal alpha-1,3-galactose is 1 % or less within said sugar chain. The sugar chain show 25 preferably the characteristics of N-linked glycans attached to Asn297 of an antibody recombinantly expressed in a CHO cell.

30 The term "the sugar chains show characteristics of N-linked glycans attached to Asn297 of an antibody recombinantly expressed in a CHO cell" denotes that the sugar chain at Asn297 of the full length parent antibody according to the invention has the same structure and sugar residue sequence except for the fucose residue as those of the same antibody expressed in unmodified CHO cells, e.g. as those reported in WO 2006/103100.

The term "NGNA" as used within this application denotes the sugar residue N-glycolylneuraminic acid.

Glycosylation of human IgG1 or IgG3 occurs at Asn297 as core fucosylated biantennary complex oligosaccharide glycosylation terminated with up to two Gal residues. Human constant heavy chain regions of the IgG1 or IgG3 subclass are reported in detail by Kabat, E.A., et al., Sequences of Proteins of Immunological Interest, 5th Ed. Public Health Service, National Institutes of Health, Bethesda, MD. (1991), and by Brüggemann, M., et al., J. Exp. Med. 166 (1987) 1351-1361; Love, T.W., et al., Methods Enzymol. 178 (1989) 515-527. These structures are designated as G0, G1 (α -1,6- or α -1,3-), or G2 glycan residues, depending from the amount of terminal Gal residues (Raju, T.S., Bioprocess Int. 1 (2003) 44-53). CHO type glycosylation of antibody Fc parts is e.g. described by Routier, F.H., Glycoconjugate J. 14 (1997) 201-207. Antibodies which are recombinantly expressed in non-glycomodified CHO host cells usually are fucosylated at Asn297 in an amount of at least 85 %. The modified oligosaccharides of the full length parent antibody may be hybrid or complex. Preferably the bisected, reduced/not-fucosylated oligosaccharides are hybrid. In another embodiment, the bisected, reduced/not-fucosylated oligosaccharides are complex.

According to the invention "amount of fucose" means the amount of said sugar within the sugar chain at Asn297, related to the sum of all glycostructures attached to Asn297 (e.g. complex, hybrid and high mannose structures) measured by MALDI-TOF mass spectrometry and calculated as average value (see e.g. WO 2008/077546). The relative amount of fucose is the percentage of fucose-containing structures related to all glycostructures identified in an N-Glycosidase F treated sample (e.g. complex, hybrid and oligo- and high-mannose structures, resp.) by MALDI-TOF.

The antibody according to the invention is produced by recombinant means. Thus, one aspect of the current invention is a nucleic acid encoding the antibody according to the invention and a further aspect is a cell comprising said nucleic acid encoding an antibody according to the invention. Methods for recombinant production are widely known in the state of the art and comprise protein expression in prokaryotic and eukaryotic cells with subsequent isolation of the antibody and usually purification to a pharmaceutically acceptable purity. For the expression of the antibodies as aforementioned in a host cell, nucleic acids encoding the respective modified light and heavy chains are inserted into expression vectors by standard methods. Expression is performed in appropriate prokaryotic or eukaryotic host cells like CHO cells, NS0 cells, SP2/0 cells, HEK293 cells, COS cells, PER.C6 cells, yeast, or E.coli cells, and the antibody is recovered from the cells

(supernatant or cells after lysis). In one embodiment the host cells are mammalian cells selected from e.g. CHO cells, NS0 cells, SP2/0 cells, HEK293 cells, COS cells, PER.C6 cells, preferably HEK293 cells or CHO cells. General methods for recombinant production of antibodies are well-known in the state of the art and described, for example, in the review articles of Makrides, S.C., *Protein Expr. Purif.* 17 (1999) 183-202; Geisse, S., et al., *Protein Expr. Purif.* 8 (1996) 271-282; Kaufman, R.J., *Mol. Biotechnol.* 16 (2000) 151-160; Werner, R.G., *Drug Res.* 48 (1998) 870-880.

The bispecific antibodies according to the invention are suitably separated from the culture medium by conventional immunoglobulin purification procedures such as, for example, protein A-Sepharose, hydroxylapatite chromatography, gel electrophoresis, dialysis, or affinity chromatography. DNA and RNA encoding the monoclonal antibodies is readily isolated and sequenced using conventional procedures. The hybridoma cells can serve as a source of such DNA and RNA. Once isolated, the DNA may be inserted into expression vectors, which are then transfected into host cells such as HEK 293 cells, CHO cells, or myeloma cells that do not otherwise produce immunoglobulin protein, to obtain the synthesis of recombinant monoclonal antibodies in the host cells.

Amino acid sequence variants (or mutants) of the bispecific antibody are prepared by introducing appropriate nucleotide changes into the antibody DNA, or by nucleotide synthesis. Such modifications can be performed, however, only in a very limited range, e.g. as described above. For example, the modifications do not alter the above mentioned antibody characteristics such as the IgG isotype and antigen binding, but may improve the yield of the recombinant production, protein stability or facilitate the purification.

The term "host cell" as used in the current application denotes any kind of cellular system which can be engineered to generate the antibodies according to the current invention. In one embodiment HEK293 cells and CHO cells are used as host cells. As used herein, the expressions "cell," "cell line," and "cell culture" are used interchangeably and all such designations include progeny. Thus, the words "transformants" and "transformed cells" include the primary subject cell and cultures derived therefrom without regard for the number of transfers. It is also understood that all progeny may not be precisely identical in DNA content, due to deliberate or inadvertent mutations. Variant progeny that have the same function or biological activity as screened for in the originally transformed cell are included.

Expression in NS0 cells is described by, e.g., Barnes, L.M., et al., *Cytotechnology* 32 (2000) 109-123; Barnes, L.M., et al., *Biotech. Bioeng.* 73 (2001) 261-270. Transient expression is described by, e.g., Durocher, Y., et al., *Nucl. Acids. Res.* 30 (2002) E9. Cloning of variable domains is described by Orlandi, R., et al., *Proc. Natl. Acad. Sci. USA* 86 (1989) 3833-3837; Carter, P., et al., *Proc. Natl. Acad. Sci. USA* 89 (1992) 4285-4289; and Norderhaug, L., et al., *J. Immunol. Methods* 204 (1997) 77-87. A preferred transient expression system (HEK 293) is described by Schlaeger, E.-J., and Christensen, K., in *Cytotechnology* 30 (1999) 71-83 and by Schlaeger, E.-J., in *J. Immunol. Methods* 194 (1996) 191-199.

The control sequences that are suitable for prokaryotes, for example, include a promoter, optionally an operator sequence, and a ribosome binding site. Eukaryotic cells are known to utilize promoters, enhancers and polyadenylation signals.

A nucleic acid is "operably linked" when it is placed in a functional relationship with another nucleic acid sequence. For example, DNA for a pre-sequence or secretory leader is operably linked to DNA for a polypeptide if it is expressed as a pre-protein that participates in the secretion of the polypeptide; a promoter or enhancer is operably linked to a coding sequence if it affects the transcription of the sequence; or a ribosome binding site is operably linked to a coding sequence if it is positioned so as to facilitate translation. Generally, "operably linked" means that the DNA sequences being linked are contiguous, and, in the case of a secretory leader, contiguous and in reading frame. However, enhancers do not have to be contiguous. Linking is accomplished by ligation at convenient restriction sites. If such sites do not exist, the synthetic oligonucleotide adaptors or linkers are used in accordance with conventional practice.

Purification of antibodies is performed in order to eliminate cellular components or other contaminants, e.g. other cellular nucleic acids or proteins, by standard techniques, including alkaline/SDS treatment, CsCl banding, column chromatography, agarose gel electrophoresis, and others well known in the art. See Ausubel, F., et al., ed. *Current Protocols in Molecular Biology*, Greene Publishing and Wiley Interscience, New York (1987). Different methods are well established and widespread used for protein purification, such as affinity chromatography with microbial proteins (e.g. protein A or protein G affinity chromatography), ion exchange chromatography (e.g. cation exchange (carboxymethyl resins), anion exchange (amino ethyl resins) and mixed-mode exchange), thiophilic adsorption (e.g. with beta-mercaptoethanol and other SH ligands), hydrophobic interaction or

aromatic adsorption chromatography (e.g. with phenyl-sepharose, aza-arenophilic resins, or m-aminophenylboronic acid), metal chelate affinity chromatography (e.g. with Ni(II)- and Cu(II)-affinity material), size exclusion chromatography, and electrophoretic methods (such as gel electrophoresis, capillary electrophoresis) (Vijayalakshmi, M.A., Appl. Biochem. Biotech. 75 (1998) 93-102).

One aspect of the invention is a pharmaceutical composition comprising an antibody according to the invention. Another aspect of the invention is the use of an antibody according to the invention for the manufacture of a pharmaceutical composition. A further aspect of the invention is a method for the manufacture of a pharmaceutical composition comprising an antibody according to the invention. In another aspect, the present invention provides a composition, e.g. a pharmaceutical composition, containing an antibody according to the present invention, formulated together with a pharmaceutical carrier.

One embodiment of the invention is the trivalent, bispecific antibody according to the invention for the treatment of cancer.

Another aspect of the invention is said pharmaceutical composition for the treatment of cancer.

Another aspect of the invention is the use of an antibody according to the invention for the manufacture of a medicament for the treatment of cancer.

Another aspect of the invention is method of treatment of patient suffering from cancer by administering an antibody according to the invention to a patient in the need of such treatment.

As used herein, "pharmaceutical carrier" includes any and all solvents, dispersion media, coatings, antibacterial and antifungal agents, isotonic and absorption delaying agents, and the like that are physiologically compatible. Preferably, the carrier is suitable for intravenous, intramuscular, subcutaneous, parenteral, spinal or epidermal administration (e.g. by injection or infusion).

A composition of the present invention can be administered by a variety of methods known in the art. As will be appreciated by the skilled artisan, the route and/or mode of administration will vary depending upon the desired results. To administer a compound of the invention by certain routes of administration, it may be necessary to coat the compound with, or co-administer the compound with, a material to prevent its inactivation. For example, the compound may be

administered to a subject in an appropriate carrier, for example, liposomes, or a diluent. Pharmaceutically acceptable diluents include saline and aqueous buffer solutions. Pharmaceutical carriers include sterile aqueous solutions or dispersions and sterile powders for the extemporaneous preparation of sterile injectable solutions or dispersion. The use of such media and agents for pharmaceutically active substances is known in the art.

The phrases "parenteral administration" and "administered parenterally" as used herein means modes of administration other than enteral and topical administration, usually by injection, and includes, without limitation, intravenous, intramuscular, intra-arterial, intrathecal, intracapsular, intraorbital, intracardiac, intradermal, intraperitoneal, transtracheal, subcutaneous, subcuticular, intra-articular, subcapsular, subarachnoid, intraspinal, epidural and intrasternal injection and infusion.

The term cancer as used herein refers to proliferative diseases, such as lymphomas, lymphocytic leukemias, lung cancer, non small cell lung (NSCL) cancer, bronchioloalviolar cell lung cancer, bone cancer, pancreatic cancer, skin cancer, cancer of the head or neck, cutaneous or intraocular melanoma, uterine cancer, ovarian cancer, rectal cancer, cancer of the anal region, stomach cancer, gastric cancer, colon cancer, breast cancer, uterine cancer, carcinoma of the fallopian tubes, carcinoma of the endometrium, carcinoma of the cervix, carcinoma of the vagina, carcinoma of the vulva, Hodgkin's Disease, cancer of the esophagus, cancer of the small intestine, cancer of the endocrine system, cancer of the thyroid gland, cancer of the parathyroid gland, cancer of the adrenal gland, sarcoma of soft tissue, cancer of the urethra, cancer of the penis, prostate cancer, cancer of the bladder, cancer of the kidney or ureter, renal cell carcinoma, carcinoma of the renal pelvis, mesothelioma, hepatocellular cancer, biliary cancer, neoplasms of the central nervous system (CNS), spinal axis tumors, brain stem glioma, glioblastoma multiforme, astrocytomas, schwannomas, ependymomas, medulloblastomas, meningiomas, squamous cell carcinomas, pituitary adenoma and Ewings sarcoma, including refractory versions of any of the above cancers, or a combination of one or more of the above cancers.

These compositions may also contain adjuvants such as preservatives, wetting agents, emulsifying agents and dispersing agents. Prevention of presence of microorganisms may be ensured both by sterilization procedures, supra, and by the inclusion of various antibacterial and antifungal agents, for example, paraben,

chlorobutanol, phenol, sorbic acid, and the like. It may also be desirable to include isotonic agents, such as sugars, sodium chloride, and the like into the compositions. In addition, prolonged absorption of the injectable pharmaceutical form may be brought about by the inclusion of agents which delay absorption such as aluminum monostearate and gelatin.

Regardless of the route of administration selected, the compounds of the present invention, which may be used in a suitable hydrated form, and/or the pharmaceutical compositions of the present invention, are formulated into pharmaceutically acceptable dosage forms by conventional methods known to those of skill in the art.

Actual dosage levels of the active ingredients in the pharmaceutical compositions of the present invention may be varied so as to obtain an amount of the active ingredient which is effective to achieve the desired therapeutic response for a particular patient, composition, and mode of administration, without being toxic to the patient. The selected dosage level will depend upon a variety of pharmacokinetic factors including the activity of the particular compositions of the present invention employed, the route of administration, the time of administration, the rate of excretion of the particular compound being employed, the duration of the treatment, other drugs, compounds and/or materials used in combination with the particular compositions employed, the age, sex, weight, condition, general health and prior medical history of the patient being treated, and like factors well known in the medical arts.

The composition must be sterile and fluid to the extent that the composition is deliverable by syringe. In addition to water, the carrier preferably is an isotonic buffered saline solution.

Proper fluidity can be maintained, for example, by use of coating such as lecithin, by maintenance of required particle size in the case of dispersion and by use of surfactants. In many cases, it is preferable to include isotonic agents, for example, sugars, polyalcohols such as mannitol or sorbitol, and sodium chloride in the composition.

As used herein, the terms "cell," "cell line," and "cell culture" are used interchangeably and all such designations include progeny. Thus, the words "transformants" and "transformed cells" include the primary subject cell and cultures derived therefrom without regard for the number of transfers. It is also

understood that all progeny may not be precisely identical in DNA content, due to deliberate or inadvertent mutations. Variant progeny that have the same function or biological activity as screened for in the originally transformed cell are included. Where distinct designations are intended, it will be clear from the context.

5 The term "transformation" as used herein refers to process of transfer of a vectors/nucleic acid into a host cell. If cells without formidable cell wall barriers are used as host cells, transfection is carried out e.g. by the calcium phosphate precipitation method as described by Graham, F.L., and van der Eb, A.J., Virology 10 52 (1973) 456-467. However, other methods for introducing DNA into cells such as by nuclear injection or by protoplast fusion may also be used. If prokaryotic cells or cells which contain substantial cell wall constructions are used, e.g. one method of transfection is calcium treatment using calcium chloride as described by Cohen, S.N, et al., PNAS 69 (1972) 2110-2114.

15 As used herein, "expression" refers to the process by which a nucleic acid is transcribed into mRNA and/or to the process by which the transcribed mRNA (also referred to as transcript) is subsequently being translated into peptides, polypeptides, or proteins. The transcripts and the encoded polypeptides are collectively referred to as gene product. If the polynucleotide is derived from genomic DNA, expression in a eukaryotic cell may include splicing of the mRNA.

20 A "vector" is a nucleic acid molecule, in particular self-replicating, which transfers an inserted nucleic acid molecule into and/or between host cells. The term includes vectors that function primarily for insertion of DNA or RNA into a cell (e.g., chromosomal integration), replication of vectors that function primarily for the replication of DNA or RNA, and expression vectors that function for transcription 25 and/or translation of the DNA or RNA. Also included are vectors that provide more than one of the functions as described.

30 An "expression vector" is a polynucleotide which, when introduced into an appropriate host cell, can be transcribed and translated into a polypeptide. An "expression system" usually refers to a suitable host cell comprised of an expression vector that can function to yield a desired expression product.

The following examples, sequence listing and figures are provided to aid the understanding of the present invention, the true scope of which is set forth in the appended claims. It is understood that modifications can be made in the procedures set forth without departing from the spirit of the invention.

Description of the Amino acid Sequences

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15
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- SEQ ID NO:1** Her3/MetSS_KHSS_FS1 - HC1 (SS_KnobsHC1_VHcMet)
- SEQ ID NO:2** Her3/MetSS_KHSS_FS1 - HC2 (SS_HolesHC2_VLcMet_FS1)
- SEQ ID NO:3** Her3/MetSS_KHSS_FS1 - LC (Her3clone29_KO1_LC)
- SEQ ID NO:4** Her3/MetSS_KHSS_FS2 - HC1 (SS_KnobsHC1_VHcMet)
- SEQ ID NO:5** Her3/MetSS_KHSS_FS2 - HC2 (SS_HolesHC2_VLcMet_FS2)
- SEQ ID NO:6** Her3/MetSS_KHSS_FS2 - LC (Her3clone29_KO1_LC)
- SEQ ID NO:7** Her3/MetSS_KHSS_PreSci - HC1 (SS_KnobsHC1_VHcMet)
- SEQ ID NO:8** Her3/MetSS_KHSS_PreSci - HC2 (SS_HolesHC2_VLcMet_PreSci)
- SEQ ID NO:9** Her3/MetSS_KHSS_PreSci - LC (Her3clone29_KO1_LC)
- SEQ ID NO:10** Her3/MetSS-3C-FS1 - HC1 (SS_KnobsHC1_VHcMet)
- SEQ ID NO:11** Her3/MetSS-3C-FS1 - HC2 (SS_HolesHC2_VLcMet_FS1)
- SEQ ID NO:12** Her3/MetSS-3C-FS1 - LC (Her3clone29_KO1_LC)
- SEQ ID NO:13** Furin specific protease cleavage site variant 1 - FS1
- SEQ ID NO:14** Furin specific protease cleavage site variant 2 - FS2
- SEQ ID NO:15** PreScission specific protease cleavage site

Experimental Procedure**Examples****Recombinant DNA techniques**

30 Standard methods were used to manipulate DNA as described in Sambrook, J., et al., Molecular cloning: A laboratory manual; Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York, 1989. The molecular biological reagents were used according to the manufacturer's instructions.

DNA and protein sequence analysis and sequence data management

General information regarding the nucleotide sequences of human immunoglobulins light and heavy chains is given in: Kabat, E.A. et al., (1991) Sequences of Proteins of Immunological Interest, Fifth Ed., NIH Publication No 91-3242. Amino acids of antibody chains are numbered according to EU numbering (Edelman, G.M., et al., PNAS 63 (1969) 78-85; Kabat, E.A., et al., (1991) Sequences of Proteins of Immunological Interest, Fifth Ed., NIH Publication No 91-3242). The GCG's (Genetics Computer Group, Madison, Wisconsin) software package version 10.2 and Infomax's Vector NTI Advance suite version 8.0 was used for sequence creation, mapping, analysis, annotation and illustration.

DNA sequencing

DNA sequences were determined by double strand sequencing performed at SequiServe (Vaterstetten, Germany) and Geneart AG (Regensburg, Germany).

Gene synthesis

Desired gene segments were prepared by Geneart AG (Regensburg, Germany) from synthetic oligonucleotides and PCR products by automated gene synthesis. The gene segments which are flanked by singular restriction endonuclease cleavage sites were cloned into pGA18 (ampR) plasmids. The plasmid DNA was purified from transformed bacteria and concentration determined by UV spectroscopy. The DNA sequence of the subcloned gene fragments was confirmed by DNA sequencing. Where appropriate and or necessary, 5'-BamHI and 3'-XbaI restriction sites were used. All constructs were designed with a 5'-end DNA sequence coding for a leader peptide, which targets proteins for secretion in eukaryotic cells.

Construction of the expression plasmids

A Roche expression vector was used for the construction of all heavy VH /or VL fusion protein and light chain protein encoding expression plasmids. The vector is composed of the following elements:

- a hygromycin resistance gene as a selection marker,
- an origin of replication, oriP, of Epstein-Barr virus (EBV),
- an origin of replication from the vector pUC18 which allows replication of this plasmid in E. coli

- a beta-lactamase gene which confers ampicillin resistance in *E. coli*,
- the immediate early enhancer and promoter from the human cytomegalovirus (HCMV),
- the human λ -immunoglobulin polyadenylation ("poly A") signal sequence, and
- unique BamHI and XbaI restriction sites.

The immunoglobulin fusion genes were prepared by gene synthesis and cloned into pGA18 (ampR) plasmids as described. The pG18 (ampR) plasmids carrying the synthesized DNA segments and the Roche expression vector were digested with BamHI and XbaI restriction enzymes (Roche Molecular Biochemicals) and subjected to agarose gel electrophoresis. Purified heavy and light chain coding DNA segments were then ligated to the isolated Roche expression vector BamHI/XbaI fragment resulting in the final expression vectors. The final expression vectors were transformed into *E. coli* cells, expression plasmid DNA was isolated (Miniprep) and subjected to restriction enzyme analysis and DNA sequencing. Correct clones were grown in 150 ml LB-Amp medium, again plasmid DNA was isolated (Maxiprep) and sequence integrity confirmed by DNA sequencing.

Transient expression of immunoglobulin variants in HEK293 cells

Recombinant immunoglobulin variants were expressed by transient transfection of human embryonic kidney 293-F cells using the FreeStyle™ 293 Expression System according to the manufacturer's instruction (Invitrogen, USA). Briefly, suspension FreeStyle™ 293-F cells were cultivated in FreeStyle™ 293 Expression medium at 37°C/8 % CO₂ and the cells were seeded in fresh medium at a density of 1-2x10⁶ viable cells/ml on the day of transfection. DNA-293fectin™ complexes were prepared in Opti-MEM® I medium (Invitrogen, USA) using 325 µl of 293fectin™ (Invitrogen, Germany) and 250 µg of heavy and light chain plasmid DNA in a 1:1 molar ratio for a 250 ml final transfection volume. "Knobs-into-hole" DNA-293fectin complexes were prepared in Opti-MEM® I medium (Invitrogen, USA) using 325 µl of 293fectin™ (Invitrogen, Germany) and 250 µg of "Knobs-into-hole" heavy chain 1 and 2 and light chain plasmid DNA in a 1:1:2 molar ratio for a 250 ml final transfection volume. Antibody containing cell culture supernatants were harvested 7 days after transfection by centrifugation at 14000 g for 30 minutes and filtered through a sterile filter (0.22 µm). Supernatants were stored at -20° C until purification.

Purification of bispecific and control antibodies

Bispecific and control antibodies were purified from cell culture supernatants by affinity chromatography using Protein A-SepharoseTM (GE Healthcare, Sweden) and Superdex200 size exclusion chromatography. Briefly, sterile filtered cell culture supernatants were applied on a HiTrap ProteinA HP (5 ml) column equilibrated with PBS buffer (10 mM Na₂HPO₄, 1 mM KH₂PO₄, 137 mM NaCl and 2.7 mM KCl, pH 7.4). Unbound proteins were washed out with equilibration buffer. Antibody and antibody variants were eluted with 0.1 M citrate buffer, pH 2.8, and the protein containing fractions were neutralized with 0.1 ml 1 M Tris, pH 8.5. Then, the eluted protein fractions were pooled, concentrated with an Amicon Ultra centrifugal filter device (MWCO: 30 K, Millipore) to a volume of 3 ml and loaded on a Superdex200 HiLoad 120 ml 16/60 gel filtration column (GE Healthcare, Sweden) equilibrated with 20mM Histidin, 140 mM NaCl, pH 6.0. Fractions containing purified bispecific and control antibodies with less than 5 % high molecular weight aggregates were pooled and stored as 1.0 mg/ml aliquots at -80°C.

Analysis of purified proteins

The protein concentration of purified protein samples was determined by measuring the optical density (OD) at 280 nm, using the molar extinction coefficient calculated on the basis of the amino acid sequence. Purity and molecular mass of bispecific and control antibodies were analyzed by SDS-PAGE in the presence and absence of a reducing agent (5 mM 1,4-dithiotreitol) and staining with Coomassie brilliant blue). The NuPAGE® Pre-Cast gel system (Invitrogen, USA) was used according to the manufacturer's instruction (4-20 % Tris-Glycine gels). The aggregate content of bispecific and control antibody samples was analyzed by high-performance SEC using a Superdex 200 analytical size-exclusion column (GE Healthcare, Sweden) in 200 mM KH₂PO₄, 250 mM KCl, pH 7.0 running buffer at 25°C. 25 µg protein were injected on the column at a flow rate of 0.5 ml/min and eluted isocratically over 50 minutes. For stability analysis, concentrations of 1 mg/ml of purified proteins were incubated at 4°C and 40°C for 7 days and then evaluated by high-performance SEC. The integrity of the amino acid backbone of reduced bispecific antibody light and heavy chains was verified by NanoElectrospray Q-TOF mass spectrometry after removal of N-glycans by enzymatic treatment with Peptide-N-Glycosidase F (Roche Molecular Biochemicals).

Example 1**Design of bispecific antibodies according to the invention**

We generated in a first attempt derivatives based on a full length antibody binding to a first antigen that carries one additional Fv as 2nd binding moiety specific for the second antigen (see Figure 2a). We introduced interchain disulfides between VHCys44 and VLCys100 ref. see p17-18 A-M. The VHCys44 of the dsFv was fused to the CH3 domain of the first heavy chain of the full length antibody, the corresponding VLCys100 module was fused to CH3 domain of the of the second heavy chain of the full length antibody.

It was previously shown that dsFvs can assemble from separately expressed modules with reasonable yields by bacterial inclusion body refolding or periplasmic secretion (WO 94/029350, US 5,747,654, Rajagopal, V., et al., Prot. Engin. 10 (1997) 1453-1459; Reiter, Y., et al., Nature Biotechnology 14 (1996) 1239-1245; Reiter, Y., et al., Protein Engineering; 8 (1995) 1323-1331; Webber, K.O., et al., Molecular Immunology 32 (1995) 249-258; Reiter, Y., et al., Immunity 2 (1995) 281-287; Reiter, Y., et al., JBC 269 (1994) 18327-18331; Reiter, Y., et al., Inter. J. of Cancer 58 (1994) 142-149; Reiter, Y., Cancer Res. 54 (1994) 2714-2718).

One bottleneck for production of linkerless dsFvs in mammalian secretion systems may be ineffective assembly of VH and VL domains without the help of chaperons: dsFv components do not contain constant regions that are recognized by BIP. (see Figure 4b) To overcome this limitation, we approached the assembly of VH and VL domains via an intermediate (Figure 4c). Therefore we connected one component (VH or VL) of the dsFv via a connector peptide to the C-terminus of one H-chain, and the corresponding other component to the C-terminus of the second H-chain by another connector peptide, which however contains on or more protease cleavage site which can be either cleaved during expression in cells (e.g. by furin) or which can be cleaved after purification in vitro. Examples of intermediate bispecific antibodies are shown in Figure 2d (for antibodies as shown in Figure 2a).

The rationale for this approach was that the effective dimerization of H-chains brings together and facilitates heterodimerization of dsFv components. To reduce nonproductive assembly of molecules containing 2 VH or 2 VL modules, complementary knobs-into-holes mutations were set into the H-chains of the IgG. These mutations were devised by Merchant, A.M., et al., Nat Biotechnol 16 (1998)

677-681 and Ridgway, J.B., et al., Protein Eng 9 (1996) 617-621 to force heterodimerization of different H-chains and consist of a T366W mutation in one H-chain chain and T366S, L368A and Y407V mutations in the corresponding other chain. Our design for generation of dsFv-containing bispecifics had the 'knobs' on the CH3 domain that was fused to VHCys44 and the complementary 'holes' were introduced into the H-chain that carried VLCys100.

Both components of the heterodimeric dsFv are tethered to CH3. This simultaneous attachment of VH and VL at their N-termini to bulky CH3 domains does not affect the structure of the Fv. However, it can restrict the accessibility towards the antigen depending (e.g. depending on the linker length or the respective antigenstructure) because the CDR region points into the direction where CH3 is located. In addition, tethering at two connection points leaves only very limited freedom for the Fv to rotate or move next to the CH3. Because of that antigens need to squeeze between CH3 and Fv. This may affect accessibility to antigen and reduce affinity, which we indeed observed for the double-connected dsFv moiety of the bispecific antibody (see SPR data in Table 2. Consistant with antigen accessibility issues due to steric hindrance, affinity determination revealed significantly reduced on-rate for the double-tethered dsFv. Nevertheless, structural integrity of the Fv appears to be intact because once the antigen has bound, the off-rate is the same as that of the unmodified antibody. The affinity values for binding of the IgG-like accessible arms of the bispecific antibody (which expectedly have full affinity), as well as for the additional double-tethered dsFv are listed in Table 2. We use the term 'restricted or reduced binding mode' for dsFv modules with reduced on-rate due to the steric hindrance after double-tethering.

Exemplarily, based on the following intermediate antibody sequences, we could express recombinantly by cleaving one linker processed after expression and purification expression antibodies according to the invention which are connected only via one domain of the disulfide-stabilized Fv fragment to the full length antibody (see also Figure 2 and the the experimental description below):

Bispecific intermediated antibody	Heavy chain construct without protease cleavage site	Heavy chain construct with protease cleavage site	Light chain (2x)
Her3/MetSS_KHSS_PreSci (protease site cleavage = prescission cleavage site)	SEQ ID NO:7	SEQ ID NO:8	SEQ ID NO:9

Exemplarily, based on the following intermediate antibody sequences, we could express recombinantly by cleaving one linker processed during expression antibodies according to the invention which are connected only via one domain of the disulfide-stabilized Fv fragment to the full length antibody (see also Figure 2 and the the experimental description below):

Bispecific intermediated antibody	Heavy chain construct without protease cleavage site	Heavy chain construct with protease cleavage site	Light chain (2x)
Her3/MetSS_KHSS_FS1 (protease cleavage = furin cleavage site-variant1)	SEQ ID NO:1	SEQ ID NO:2	SEQ ID NO:3
Her3/MetSS_KHSS_FS2 (protease cleavage site = furin cleavage site –variant 2)	SEQ ID NO:4	SEQ ID NO:5	SEQ ID NO:6

Example 2

a) Expression and purification of bispecific antibodies according to the invention in a two-step or one-step process

two-step process:

1. Step: Transient expression

Transient expression was applied for production of secreted bispecific antibody derivatives. Plasmids encoding L-chains and modified H-chains were co-transfected into HEK 293 suspension cells. Culture supernatants containing secreted antibody derivatives were harvested one week later. These supernatants

could be frozen and stored at -20C before purification without affecting yields. The bispecific antibodies were purified from supernatants by Protein A and SEC in the same manner as conventional IgGs which proves that they were fully competent to bind Protein A. Expression yields within cell culture supernatants were lower than transiently expressed unmodified antibodies but still within a reasonable range. After completion of all purification steps, yields between 4 and 10 mg/L of homogenous protein were obtained. Despite having no peptide linker between VH and VL of the additional dsFv moiety, stability analyses revealed no indication for unusual concentration- or temperature dependent disintegration or aggregation. The proteins were stable and freeze-thaw was well tolerated. Size, homogeneity, and composition of trivalent bispecific antibody derivatives and their components under reducing and non-reducing conditions are shown in Figure 5 and 6. The identity and composition of each protein was confirmed by mass spectrometry (Table 1).

Double-tethering of dsFv components to CH3-domains reduces antigen access and thereby inactivates the functionality of the dsFv. Free rotation of Fvs around one connector peptide would most likely dramatically increase access to antigen, but the fusion of dsFv at two connection points does not permit a large degree of flexibility or rotation. To re-activate the inactivated binding functionality of such restricted dsFvs moieties, we introduced specific protease recognition sites into one of the connector peptides (schematically shown in Figure 4d). Our rationale for that approach was to utilize proteolytic cleavage for the release of just one of the 2 connections. Upon proteolytic processing, the dsFv would still be covalently linked to the IgG backbone of the bispecific antibody by its other connector. But in contrast to double-connection, attachment at just one flexible connection point can improve flexibility allow free rotation to facilitate access to antigen. Figure 1b shows different connector sequences that we applied to enable processing by proteases. The standard non-cleavable connector is composed of six Gly4Ser-repeats, a motif that has been frequently used for generation fusion proteins composed of different domains. For proteolytic processing, we introduced specific recognition sequences into the central region of this connector:

One connector contains a site that is cleaved by the Prescission protease. This protease can unleash functionality of Fv modules that are expressed in restricted form. PreScission Protease (GE Healthcare Catalogue No. 27-0843-01) is a genetically engineered fusion protein consisting of human rhinovirus 3C protease and GST. This protease was specifically designed to facilitate removal of the protease by allowing simultaneous protease immobilization and cleavage of GST

fusion proteins produced from the pGEX-6P vectors pGEX-6P-1, pGEX-6P-2, and pGEX-6P-3; see pGEX Vectors (GST Gene Fusion System). PreScission Protease specifically cleaves between the Gln and Gly residues of the recognition sequence of LeuGluValLeuPheGln/GlyPro (Walker, P.A., et al. BIO/TECHNOLOGY 12, (1994) 601-605; Cordingley, M. G. et al. J. Biol. Chem. 265, (1990) 9062-9065.)

2. Step: proteolytic processing (cleavage)

Processing with Prescission can be applied after or during purification.

one-step process:

To realize the proteolytic cleavage during the expression step we used linker sequences can be recognized and cleaved by Furin. Furin is a protease that is present in endosomal and secretory compartments and the trans-Golgi network of mammalian cells, incl. HEK293. We chose such protease sites to enable dsFv processing within the expression process. Bispecific entities carrying the restricted dsFv will encounter furin during secretion. Thereby, already cleaved fully functional proteins can be made by the cells.

Bispecific antibodies containing a prescission site are expressed in restricted form and can be activated in downstream processing

One application of bispecific antibody formats that contain restricted binding modules is to express them in restricted form and activate them afterwards as one step in downstream processing. This application has advantages in cases where high activity of binding modules poses a problem for expression, e.g. because full functionality would interfere with cell growth, with secretion processes, or is toxic to producer cells.

As an example for this setting, we expressed and purified a Her3-cMet bispecific antibody carrying a restricted cMet dsFv module, and subsequently unleashed the dsFv activity by processing with Prescission. Figure 5 shows that after expression and purification from cell culture supernatants, bispecific Her3-cMet entities are obtained which have the components of the dsFv tightly connected to H-chains. Reduced SDS-PAGE show (in addition to the standard L-chain of the Her3-entity), the presence of a protein (double-)band at the height of 65 kD. This band represents the H-chains (50 kD) that carry additional connector peptides (2 kD) and VH or VL domains (13 kD) at their C-termini.

The affinity (prior to Prescission processing) of these bispecific molecules towards their fully accessible binding entities to Her 3 is the same as that of the wildtype antibody (Table 1). In contrast, the affinity of the restricted dsFv moiety towards cMet is compromised due to steric hindrance. Biacore analyses show a > 20fold fold reduced affinity than that of the Wildtype Fab (Table 1).

Table 1: Exemplary expression and purification of bispecific antibody derivatives

Molecule	Connector	Processing	Yield (mg/L)	SDS-PAGE & Mass Spec
Her3/MetSS_KHSS_PreSci	Prescission site	none	4-20 mg/L	L + extended H
Her3/MetSS_KHSS_PreSci	Prescission site	PreScission		L + extended H + cleaved H + VL
Her3/MetSS_KHSS_F1	Furin site-variant 1	During expresseion	4 mg/L	L + H + extended H + VL

Cleavage of the prescission site within the connector between CH3 and VL resolves the restriction of the dsFv and gives rise to molecules that have the dsFv attached to the IgG by only by one connector. Reducing SDS PAGE proves that after cleavage, one of the extended H-chains is converted to normal size (52 kd) and an additional VL domain of 13 k (see Figure 6a). While cleaved, the molecule is still held together by a stable disulfide bond as shown by size exclusion chromatography and mass spectroscopy.

A comparison of affinities of restricted and processed forms of the bispecific antibody is listed in Table 2.: as expected, processing at the dsFv moiety did not change the binding to the previously already fully accessible antigen Her3. On the other hand, resolution of steric hindrance by cleaving one connector greatly improved the on-rate of the linkerless dsFv module: the affinities of the unleashed dsFv were improved > 30 fold and were fully restored to affinity levels of the parent antibody (Table 2).

Table 2: Binding affinity of bispecific antibody derivatives according to the invention (and comparison with parent antibodies as well as ,where possible (e.g. for prescission sites), comparison with corresponding intermediates before protease cleavage)

	HER3 binding affinity (KD)			cMet binding affinity (KD)		
Bispecific Antibody according to the invention	ka (1/Ms)	kd (1/s)	KD (M)	ka (1/Ms)	kd (1/s)	KD (M)
Her3_MetSS_KHSS_ FS1 (protease cleavage during expression)	1.65E+0 5	3.38E- 04	2,05E-09	3.12E+04	1.88E- 04	6.05E-09
Her3_MetSS_KHSS_ FS2 (protease cleavage during expression)	n.d.	n.d.	n.d.	2.74E+04	1.93E- 04	7.05E-09
Her3-cMet-3C-FS1 (protease cleavage during expression)	1.,63E+ 05	3,41E- 04	2,09E-09	1.74E+04	3.,31E -04	1.,90E-08
Her3_MetSS_KHSS_ PreSci_digested (after purification and protease cleavage)	1,76E+0 5	3,56E- 04	2,02E-09	2.43E+04	2.03E- 04	8.35 E-09
Intermediate for Bispecific Antibody according to the invention						
Her3_MetSS_KHSS_ PreSci (purified intermediate)	1,72E+0 5	4,14E- 04	2,40E-09	5.33E+02	1.97E- 04	3.69 E-07
Parent monospecific Antibody						
Parent cMet-Fab	-	-	-	6,92E+04	1,59E- 04	2,29E-09
Parent Mab_Her3_001 clone 29	1,52E+0 5	3,60E- 04	2,36E-09	-	-	-

Bispecific antibodies containing furin sites become effectively processed during expression and display full functionality of the linkerless dsFv

5 Furin sites within connectors can be used for direct expression of bispecific antibodies containing linkerless dsFvs with unrestricted functionality. Furin is present in endocytic and secretory vesicles, in the trans-Golgi network and in some cases on cell surfaces of many mammalian cells (e.g HEK293 as used within these experiments). Its recognition sites frequently contain the motif RXK/RR which are present in a variety of secreted precursor proteins such as pro-TGF β 1 or pro-van
10 Willebrand factor. Therefore, we selected these recognition sequences for generating two furin site containing connector sequences (Furin specific protease cleavage site variant 1 - FS1 of SEQ ID NO:13 and Furin specific protease cleavage site variant 2 – FS2 of SEQ ID NO:14).

15 Because furin is present in the trans-Golgi network and in secretory vesicles, cleavage can occur within cells during the production. The expression yields of furin processed unrestricted and fully functional molecules that we obtained was similar to that observed for restricted molecules (Table 1), because the dsFvs become fully folded and assembled prior to encountering compartments with Furin activity. Figures 5 and 6b proves that after expression and purification molecules
20 are obtained which are already quantitatively processed. Reducing PAGE shows (in addition to the standard <Her3> L-chain) one extended H-chain of 65 kD that carries the VH of the dsFv, and another H-chain that has been converted to normal size (52 kD) by furin. The additional VL domain of 13 kD is also detectable. Since the purification procedure involved ProteinA and SEC (both of which would not
25 recover unlinked VL domains), detection of these domains indicate the generation of fully processed functional bispecifics. Size exclusion chromatography and mass spectroscopy further confirmed the fact that all domains are held together by stable disulfides (schematically shown in Figures 2 and 3).

30 Because the processing via Furin occurs during the expression process, the preparations obtained after purification should be composed of bispecific entities with fully active linkerless dsFvs in unleashed form. This could be confirmed by SPR analyses (Table 2). All binding entities of the bispecific antibody, those recognizing Her3 as well as the dsFv that binds cMet, have unrestricted binding capability. Their affinity to Her3 and cMet is comparable to that of unmodified
35 antibodies or Fab (Table 2).

Application of mass spectrometry to analyze furin-mediated processing of bispecific antibody derivatives during expression in mammalian cells

The bispecific antibody derivatives that we describe in this application are translated to protein as precursor forms. These need cleavage by furine within the secretory pathway of producer cells for conversion into an unrestricted format. To determine the degree of furin-mediated conversion of restricted precursor forms of the bispecific antibodies to unrestricted molecules, we applied mass spectrometry. This technology can be used to determine the exact molecular mass of proteins and protein fragments.

Prior to the mass spectrometric analysis, the antibodies were deglycosylated applying standard protocols using N-Glycosidase F in order to decrease spectral complexity and facilitate data interpretation. As a further measure to facilitate data interpretation, molecules to be analyzed were cleaved by IdeS protease into disulfide-bridged Fc and F(ab)₂ fragments. The fragments were subsequently reduced with TCEP to separate their different components to facilitate identification and characterization. Thereby, relevant furin cleavage events are detectable as defined masses of the deglycosylated and reduced IdeS-derived Fc fragments.

The samples were desalted and subsequently subjected to electrospray ionization (ESI) mass spectrometry on a Quadrupole Time-of-Flight instrument (Q-Star, (ABI, Darmstadt) or Maxis (Waters, Manchester). A NanoMate system (Triversa NanoMate System, Advion, Ithaka, USA) was used to introduce the samples into the ESI nanospray source. The samples were analyzed using standard MS protocols for deglycosylated and reduced antibodies providing a stable spray, proper desolvation and no fragmentation of the analytes. The mass spectra were acquired with scan durations of 5 seconds.

The results of these analyses indicate that the bispecific antibody derivatives that are translated as precursor forms are thereafter processed by furine within the secretory pathway of producer cells. The protein preparations Her3_MetSS_KHSS_FS1 and Her3_MetSS_KHSS_FS2 have two different furin recognition sequences inserted within their connectors (in heavy chain fusion proteins of SEQ ID NO:2 for FS1 and of SEQ ID NO:4 for FS2). In both preparations, complete processing by furin was observed and unprocessed precursor fragments (extended IdeS-Fc fragments) were not detectable. In addition, our mass analyses indicated further carboxyterminal processing of the

furin-cleaved protein modules. The arginine and/or lysine residues that preceded the cleavage site and formed part of the furine recognition sequence were quantitatively removed from the furin-processed products.

5 Another protein preparation of a bispecific antibody derivative that we analyzed harbored a connector sequence of reduced length (Her3-cMet-3C-FS1).

Bispecific intermediate antibody	Heavy chain construct without protease cleavage site	Heavy chain construct with protease cleavage site	Light chain (2x)
Her3/MetSS-3C-FS1 (protease cleavage = furin cleavage site-variant1)	SEQ ID NO:10	SEQ ID NO:11	SEQ ID NO:12

10 In this preparation, again products of furin processing were unambiguously detected. Furthermore, and in the same manner as described above, arginine and/or lysine residues that preceded and formed part of the furine recognition sequence were also quantitatively removed from the furin-processing products. This preparation contained in addition to furin-processing products additional extended Fc fragments. This indicates that this protein batch contained still some unprocessed precursor molecules.

15 To further analyze the degree of processing vs presence of unprocessed precursor molecules in this Her3-cMet-3C-FS1 preparation, SDS-PAGE analyses were performed under reducing conditions. The results of these analyses (Figure 9) indicate a significant degree of furin processing also for this preparation: Furin cleavage converts only one of the extended H chain (63kD) to a H-chain of normal size (50kD) and releases a protein fragment of 12 kD. Both products of this processing process are clearly detectable.

20 The ratio between fully processed products and any remaining unprocessed precursor-material cannot be determined in an exact manner by this method because the complementary (uncleavable) extended H-chain locates at the same position in the gel as the precursor. However, the detectable amounts of processing products, especially the clear visualization of the 12kD fragment (which due to its small size is much more difficult to visualize than larger protein fragments),
25 indicate that quite effective processing has taken place even in this preparation.

Functionality of the obtained bispecific antibodies according to the invention

The functionality of the obtained bispecific antibodies according to the invention (which are connected only via one domain of the disulfide-stabilized Fv fragment to the full length antibody) was further investigated in cellular assays: FACS experiments (Figure 7) showed that unrestricted arms of bispecific antibodies specifically bound to Her3-expressing cancer cells and caused accumulation on such cells. The binding of restricted versus unleashed dsFv cMet modules was analysed by FACS on cMet expressing A549 cells in a similar manner. Figure 7 shows that cleavage with furin during expression or with Prescission after expression significantly improves the c-Met dependent accumulation on A549 cells compared to restricted dsFv modules. Furthermore, for the cMet module functionality regarding interference with signaling pathways could be demonstrated for the unleashed dsFv module that recognizes cMet: Unrestricted cMet dsFv (via Furin cleavage or Prescission cleavage) interfered with HGF-mediated ACT signaling as efficiently as the monovalent Fab derived from the parent antibody (Figure 8). In contrast, restricted dsFv modules had dramatically reduced activity which correlated with their reduced affinity.

Example 3**Generation and biochemical characterization of additional bispecific antibodies that are processed during expression.**

To demonstrate that the design and process of production of bispecific antibodies according to the invention is generalizable, we designed, produced and characterized various additional bispecific antibodies. All of these were generated as precursor molecules containing disulfide-stabilized Fv entities (as described above) connected via one furin cleavable and one noncleavable peptide sequence to IgG derivatives. These bispecific antibody derivatives were composed of binding modules that address cell surface antigens on tumors (as target 1) as well as anti-digoxigenin binding entities (as target 2). The cell surface targeting specificities addressed either the cancer associated LeY carbohydrate antigen (LeY), CD22, CD33, Her2 or IGF1R antigens which are also expressed on cancer cells, or the VEGFR2 which is expressed in many tumors. The sequences of antibodies with these binding specificities, as well as the corresponding Dig.-binding antibody derivative have been previously described (see WO 2011/003557), and can be derived therefrom. The composition of the combined molecules with dual functionalities according to our invention is exemplarily shown in Figure 10.

Expression and purification of these furin-processed bispecific antibody derivatives was performed as described in Example 2. Expression yield per liter cell culture supernatant were in the same range (7-40 mg/L) as those observed for many unmodified antibodies. All bispecific antibody derivatives could be purified to homogeneity and all protein preparations contained no or only minute amounts of aggregates. In many preparations no aggregates were detectable at all, as shown by SEC analyses of these preparations in Figure 11. The expression yields of purified homogenous antibody per liter culture supernatant were 15 mg/L for LeY-Dig, 19.5 mg/L for CD22-Dig, 40mg/L for CD33-Dig, 40.2 mg/L for VEGFR2-Dig, 25mg/L for Her2-Dig and 7mg/L for IGF1R-Dig.

The presence of the furin recognition site in one of the peptide connectors that fuses dsFv to the IgG backbone leads as desired to complete proteolytic processing during the expression process. This was demonstrated by reducing and non-reducing SDS-PAGE analyses: disulfide-bonded bispecific antibodies of large size are seen under nonreducing conditions, which separate into separate chains of expected molecular weight upon reduction (Figure 12). Furin cleavage converts only one of the extended H chain (63kD) to a H-chain of normal size (50kD) and releases a protein fragment of 12 kD. Both products of this processing process are clearly detectable in the reducing gel.

The defined composition and homogeneity of protein products was further confirmed by mass spectrometry (Figure 13) to determine the exact molecular mass of proteins and protein fragments. Prior to the mass spectrometric analysis, the antibodies were deglycosylated applying standard protocols using N-Glycosidase F in order to decrease spectral complexity and facilitate data interpretation. As a further measure to facilitate data interpretation, molecules to be analyzed were cleaved by IdeS protease into disulfide-bridged Fc and F(ab)₂ fragments. The fragments were subsequently reduced with TCEP to separate their different components to facilitate identification and characterization as described above, thereafter desalted and subsequently subjected to electrospray ionization (ESI) mass spectrometry. The results of these analyses indicate that all analyzed bispecific antibody derivatives that are translated as precursor forms are thereafter processed by furine within the secretory pathway of producer cells. The protein preparations showed complete processing by furin (within detection limits) and unprocessed precursor fragments (extended IdeS-Fc fragments) were not detectable. In addition, our mass analyses indicated further carboxyterminal processing of the furin-cleaved protein modules. The arginine and/or lysine

residues that preceded the cleavage site and formed part of the furin recognition sequence were quantitatively removed from the furin-processed products.

These results prove that our design and process of production of bispecific antibodies according to the invention is generalizable: various bispecific antibodies that contain furin recognition sites within connector peptides can be generated, produced and purified to homogeneity.

Example Y

Functional characterization of additional bispecific antibodies that are processed during expression.

The functionality of additional bispecific antibodies (which are connected only via one domain of the disulfide-stabilized Fv fragment to the full length antibody) was investigated in binding assays via surface Plasmon resonance. Because the processing via Furin occurs during the expression process, the preparations obtained after purification should be composed of bispecific entities with fully active linkerless dsFvs. Full binding competency was confirmed by SPR analyses which showed that all binding entities of the bispecific antibody as well as the dsFv that binds Digoxigenin, have unrestricted binding capability. Their affinity to target antigen 1 and to the target antigen 2 Digoxigenin is comparable to that of unmodified antibodies or Fab. For example, the individual binding affinity for Digoxigeninylated payload of bispecific antibody derivatives according to the invention in comparison with parent antibodies were K_d 22 nM for the control molecule and 19 nM for the furin-processed molecule (Figure 14). Furthermore, these SPR experiments in Figure 14b and in Figure 15b clearly demonstrated that the bispecific antibody derivatives simultaneously bind two different antigens. This was shown for target 1 antigen LeY as well as CD22 (Figure 14 and in Figure 15).

The functionality of the bispecific antibody that binds LeY as well as Dig (which are connected only via one domain of the disulfide-stabilized Fv fragment to the full length antibody) was further investigated in cellular assays: FACS experiments (Figure 16) showed that the bispecific antibody that were designed and generated according to the invention bind specifically to LeY antigen expressing MCF7 target cells. This is shown via secondary antibodies (Figure 16a), which demonstrate that the LeY-binding capability of the furin-processed bispecific antibodies is indistinguishable from the original LeY-binding antibody. Furthermore, these bispecific antibodies are able to direct fluorescent payloads that are bound by the 2nd specificity (Dig-Cy5) to these target cells, which is shown in Figure 16b.

5 Thereby, Dig-conjugated payloads are enriched on target cells but not on cells that do not express target antigen. Quantitative binding and cellular accumulation of Dig-Payload is further demonstrated by the fact that the targeted fluorescence on cells is twice as high for modules with two Dig-binding entities compared to bispecifics that possess only one Dig-binding entity.

10 These results prove that our design and process of production of bispecific antibodies according to the invention is generalizable: various bispecific antibodies that contain furin recognition sites within connector peptides can be generated, which retain full binding activity towards target 1 as well as towards target 2.

10

Patent Claims

1. A bispecific antibody comprising
 - a) a full length antibody specifically binding to a first antigen and consisting of two antibody heavy chains and two antibody light chains;
 - 5 b) a Fv fragment specifically binding to a second antigen comprising a VH^2 domain and a VL^2 domain, wherein both domains are connected via a disulfide bridge, and

wherein only either the VH^2 domain or the VL^2 domain is fused via a peptide linker to the heavy or light chain of the full length antibody

10 specifically binding to a first antigen.
2. The bispecific antibody according to claim 1 characterized in that the bispecific antibody is trivalent and either the VH^2 domain or the VL^2 domain is fused via a peptide linker to the heavy chain of the full length antibody specifically binding to a first antigen.
- 15 3. The bispecific antibody according to claim 2 characterized in that the VH^2 domain or VL^2 domain is N-terminally fused via a peptide linker to the C-terminus of the full length antibody specifically binding to a first antigen.
4. The bispecific antibody according to claims 2, characterized in that
- 20 the VH^2 domain or VL^2 domain is C-terminally fused via a peptide linker to the N-terminus of the full length antibody specifically binding to a first antigen.
5. The bispecific antibody according to claims 1, characterized in that the VH^2 domain or VL^2 domain is N-terminally fused via a peptide linker to the
- 25 C-terminus of the heavy or light chain of the full length antibody specifically binding to a first antigen.

6. The bispecific antibody according to claims 1, characterized in that
the VH^2 domain or VL^2 domain is C-terminally fused via a peptide linker to
the N-terminus of the heavy or light chain of the full length antibody
specifically binding to a first antigen.
- 5 7. The bispecific antibody according to claims 1 to 6, characterized in that
the VH^2 domain and the VL^2 domain are connected
via a disulfide bridge which is introduced between the following positions:
i) VH^2 domain position 44 and VL^2 domain position 100,
ii) VH^2 domain position 105 and VL^2 domain position 43, or
10 iii) VH^2 domain position 101 and VL^2 domain position 100.
8. The bispecific antibody according to claims 1 to 6, characterized in that
the VH^2 domain and the VL^2 domain are connected
via a disulfide bridge which is introduced between the positions
 VH^2 domain position 44 and VL^2 domain position 100.
- 15 9. The bispecific antibody according to claims claims 1 to 8 characterized in
that
the first CH3 domain of the heavy chain of the whole antibody and the
second CH3 domain of the whole antibody each meet at an interface which
comprises an alteration in the original interface between the antibody CH3
20 domains;
wherein i) in the CH3 domain of one heavy chain,
an amino acid residue is replaced with an amino acid residue having a larger
side chain volume, thereby generating a protuberance within the interface of
the CH3 domain of one heavy chain which is positionable in a cavity within
25 the interface of the CH3 domain of the other heavy chain
and
ii) in the CH3 domain of the other heavy chain,
an amino acid residue is replaced with an amino acid residue having a
smaller side chain volume, thereby generating a cavity within the interface of

the second CH3 domain within which a protuberance within the interface of the first CH3 domain is positionable.

10. The bispecific antibody according to claim 9 characterized in that

5 said amino acid residue having a larger side chain volume is selected from the group consisting of arginine (R), phenylalanine (F), tyrosine (Y), and tryptophan (W) and said amino acid residue having a smaller side chain volume is selected from the group consisting of alanine (A), serine (S), threonine (T), and valine (V).

11. The bispecific antibody according to claim 9 characterized in that

10 both CH3 domains are further altered by the introduction of a cysteine (C) residue in positions of each CH3 domain such that a disulfide bridge between the CH3 domains can be formed.

12. A method for the preparation of the bispecific antibody according to any of claims 1 to 11 comprising the steps of

15 A) expressing in a mammalian cell nucleic acid encoding a bispecific antibody comprising

a) a full length antibody specifically binding to a first antigen and consisting of two antibody heavy chains and two antibody light chains;

20 b) a Fv fragment specifically binding to a second antigen comprising a VH² domain and a VL² domain, wherein both domains are connected via a disulfide bridge, and

wherein the Fv fragment is fused

25 via the N-termini of the VH² domain and the VL² domain to the both C-termini of the heavy chain of the full length antibody specifically binding to a first antigen via a first and second peptide linker to, or

30 via the C-termini of the VH² domain and the VL² domain to the both N-termini of one heavy and one light chain of the full length antibody specifically binding to a first antigen via a first and second peptide linker,

characterized in that

one of the linkers comprises a protease cleavage site cleavable by furin, and the other linker does not comprise a protease cleavage site;

5 B) recovering said antibody from said cell or the cell culture supernatant.

13. A method for the preparation of the trivalent, bispecific antibody according to any of claims 2 to 4 and 7 to 11 comprising the steps of

A) expressing in a mammalian cell nucleic acid encoding a bispecific antibody comprising

10 a) a full length antibody specifically binding to a first antigen and consisting of two antibody heavy chains and two antibody light chains;

b) a Fv fragment specifically binding to a second antigen comprising a VH^2 domain and a VL^2 domain, wherein both domains are connected via a disulfide bridge, and

15 wherein the Fv fragment is fused

via the N-termini of the VH^2 domain and the VL^2 domain to the both C-termini of the heavy chains of the full length antibody specifically binding to a first antigen via a first and second peptide linker to, or

20

via the C-termini of the VH^2 domain and the VL^2 domain to the both N-termini of the heavy chains of the full length antibody specifically binding to a first antigen via a first and second peptide linker,

characterized in that

25 one of the linkers comprises a protease cleavage site cleavable by Prescission protease, and the other linker does not comprise a protease cleavage site;

B) recovering said antibody from said cell or the cell culture supernatant.

14. The method according to claim 12 or 13 characterized in that

30 the protease cleavage site cleavable by furin is SEQ ID NO:13 or SEQ ID NO:14.

- 60 -

15. The method according to claim 12 or 13 characterized in that the protease cleavage site cleavable by Prescission protease is SEQ ID NO:15.
16. The method according to any of claims 12 to 15 characterized in that
5 the mammalian cell is a CHO cell, NS0 cell, SP2/0 cell, HEK293 cell, COS cell or PER.C6 cell.
17. An antibody obtained by the methods according to any of claims 12 to 16
18. A pharmaceutical composition comprising the bispecific antibody according to any of claims 1 to 11.

Fig. 1

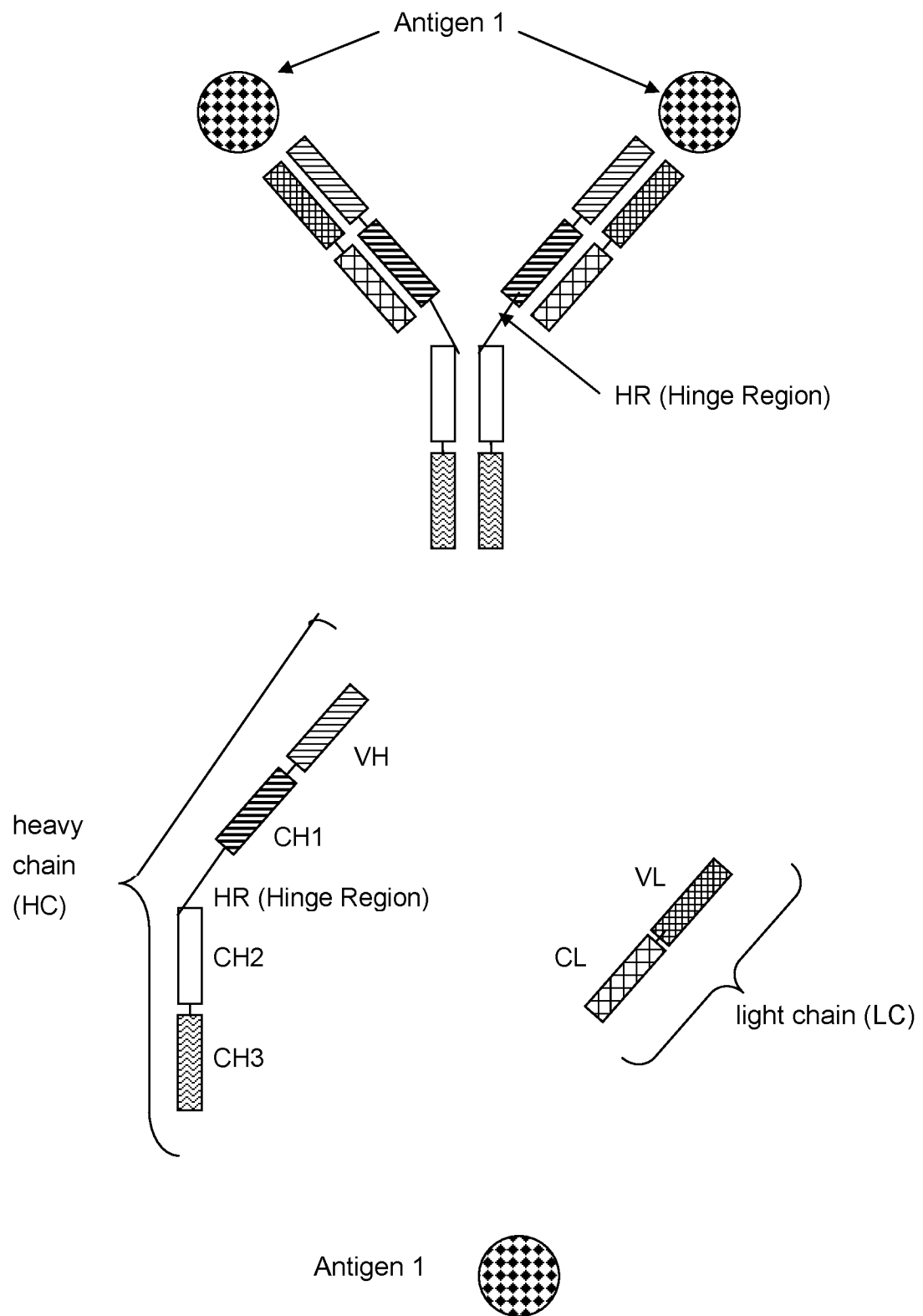


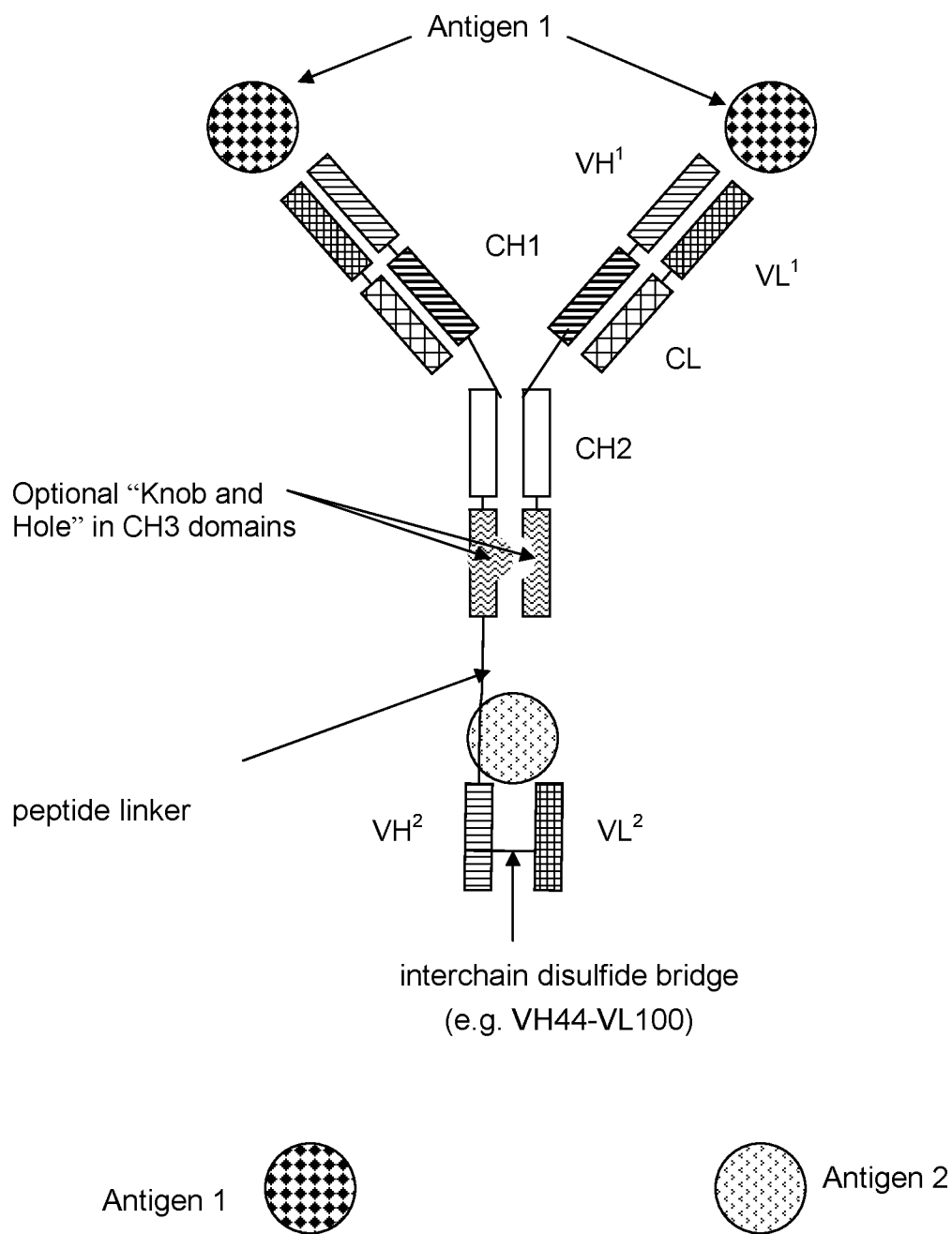
Figure 2a

Figure 2b

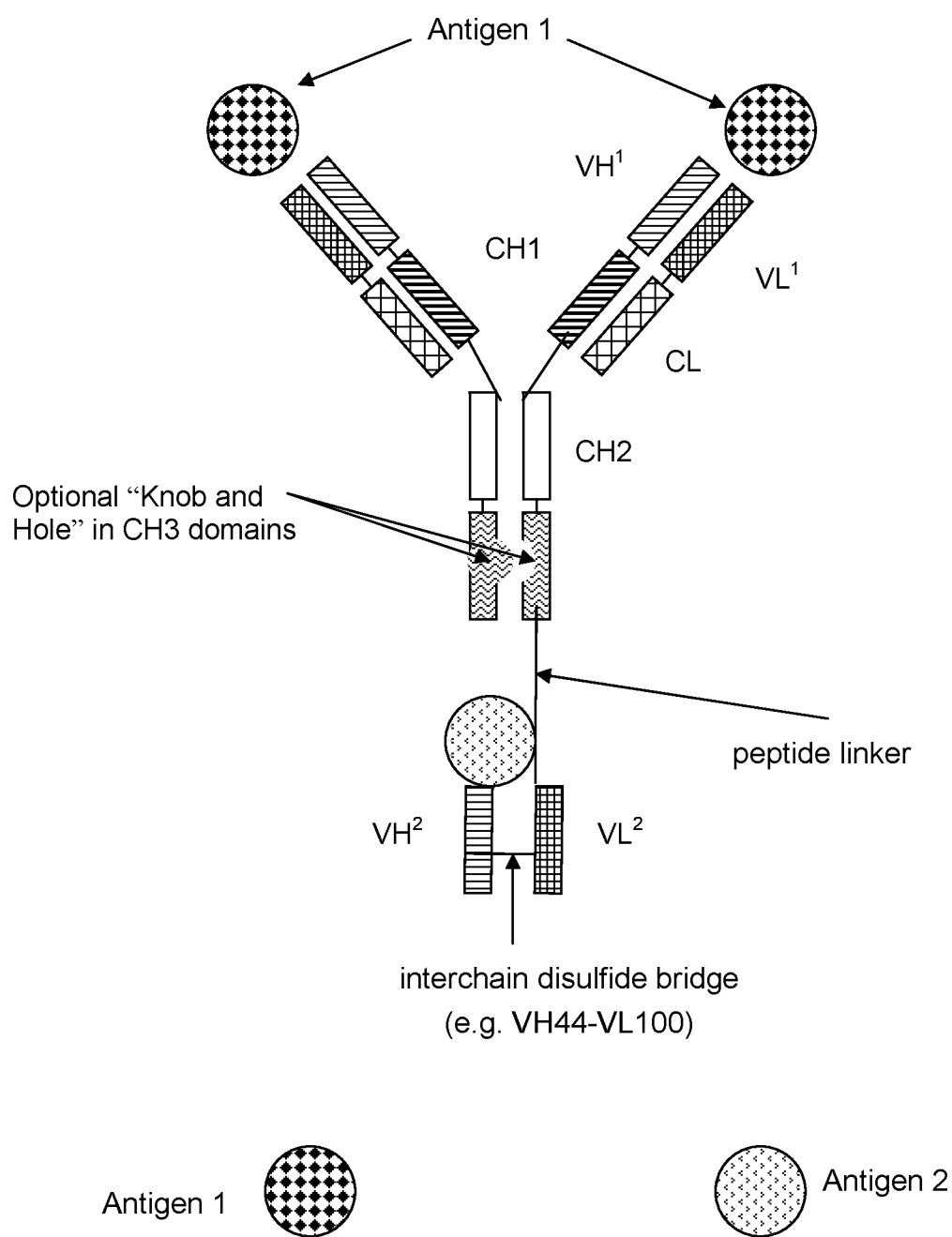


Figure 2c

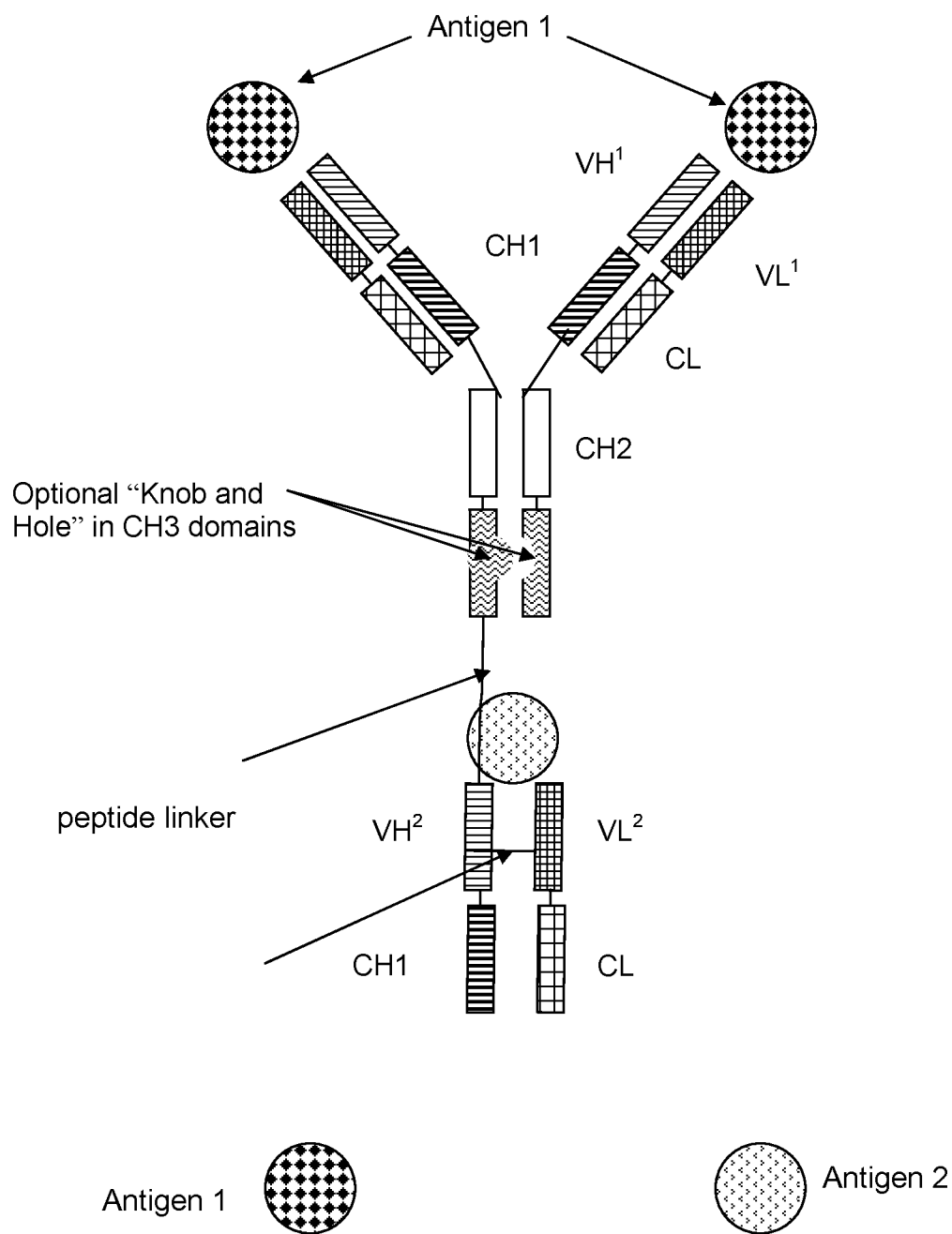


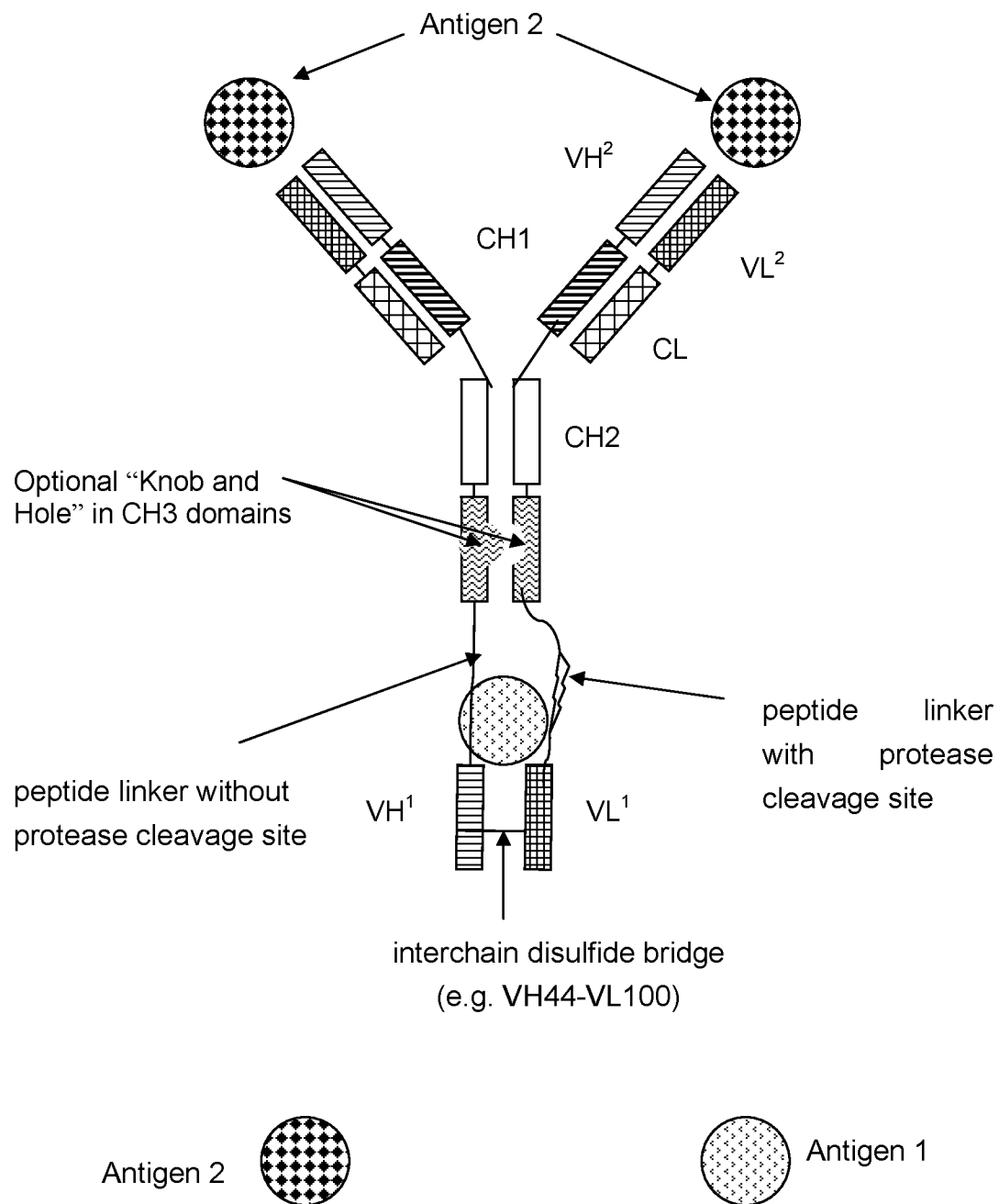
Figure 2d

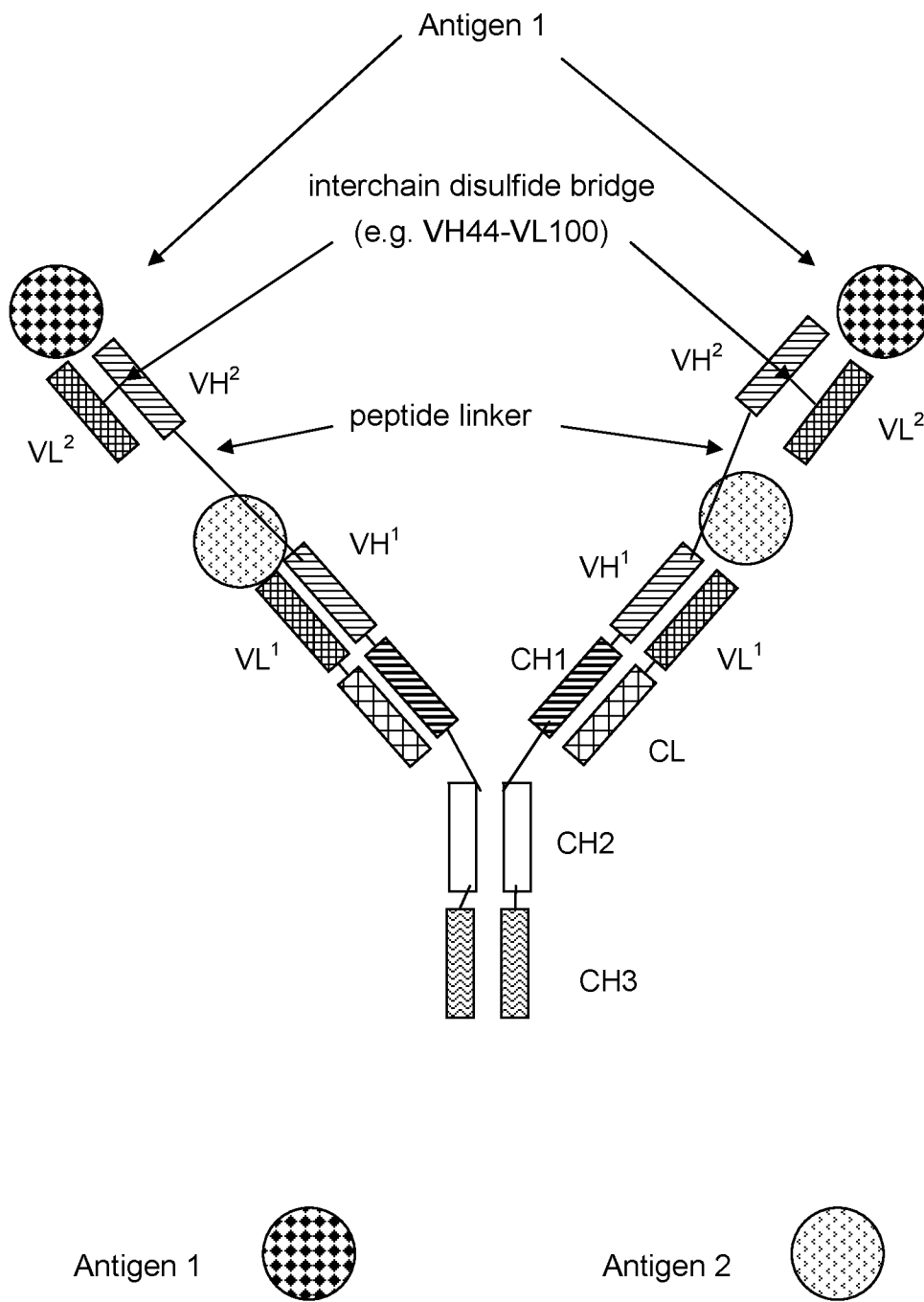
Figure 3a

Figure 3b

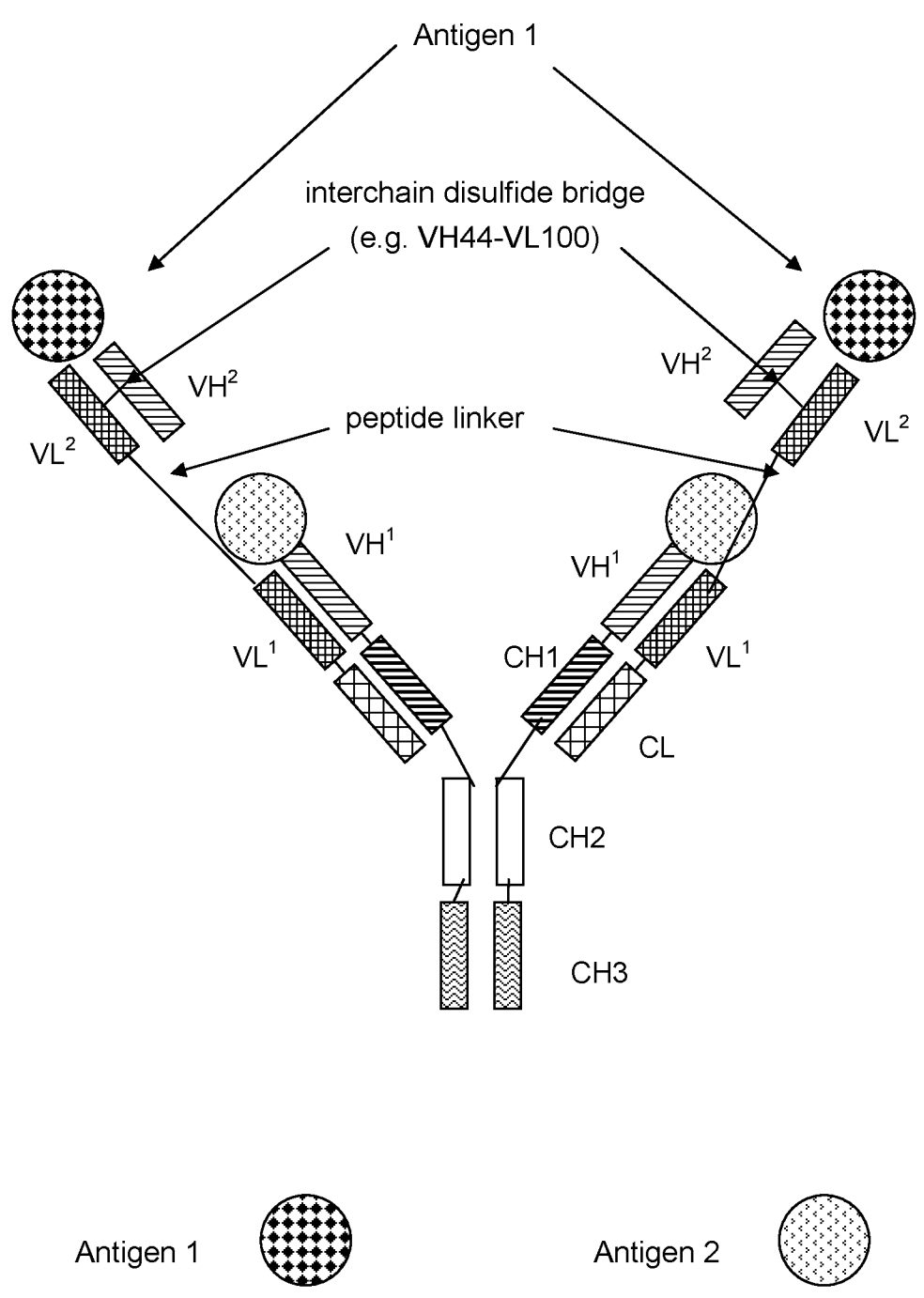


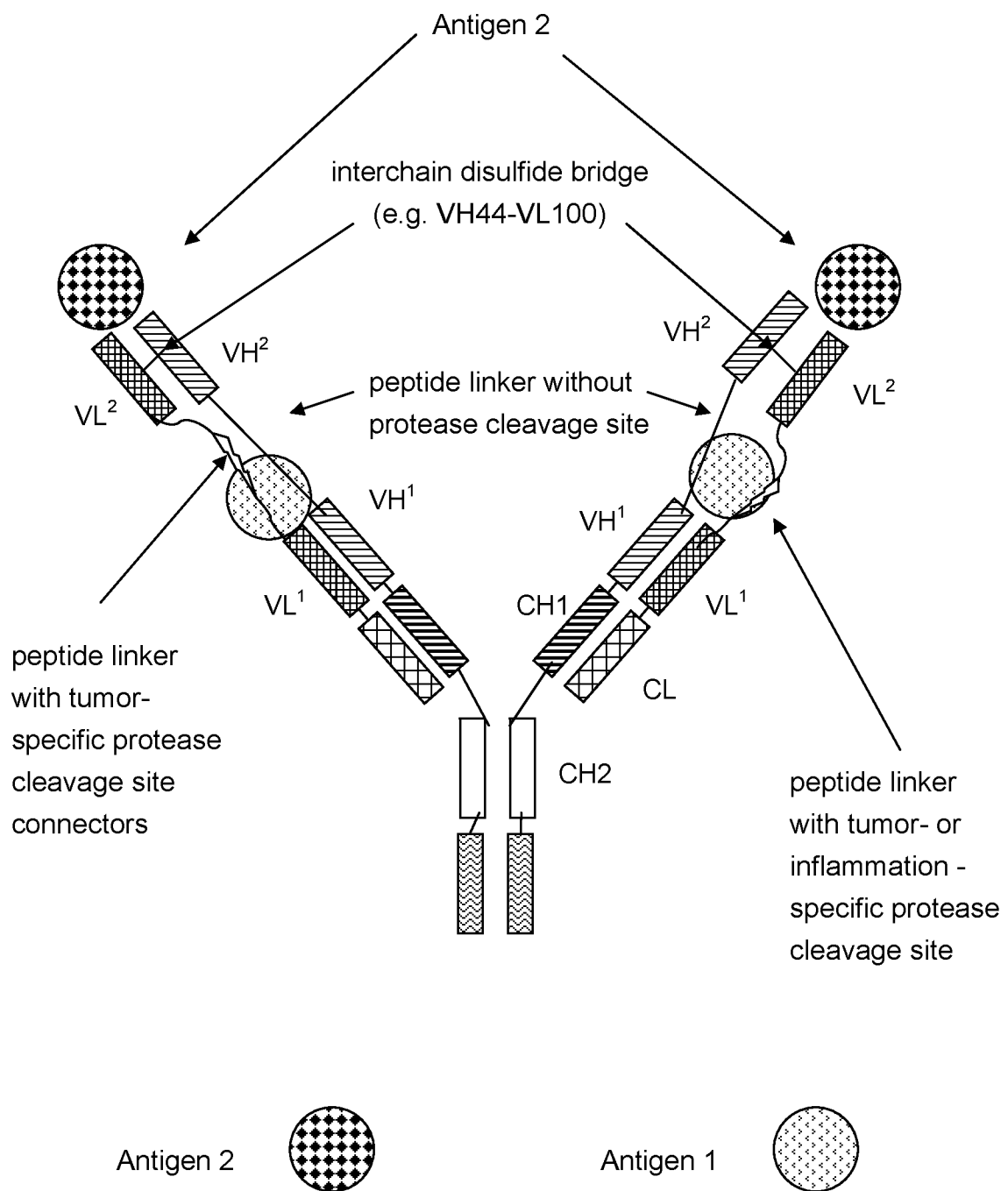
Figure 3c

Figure 3d

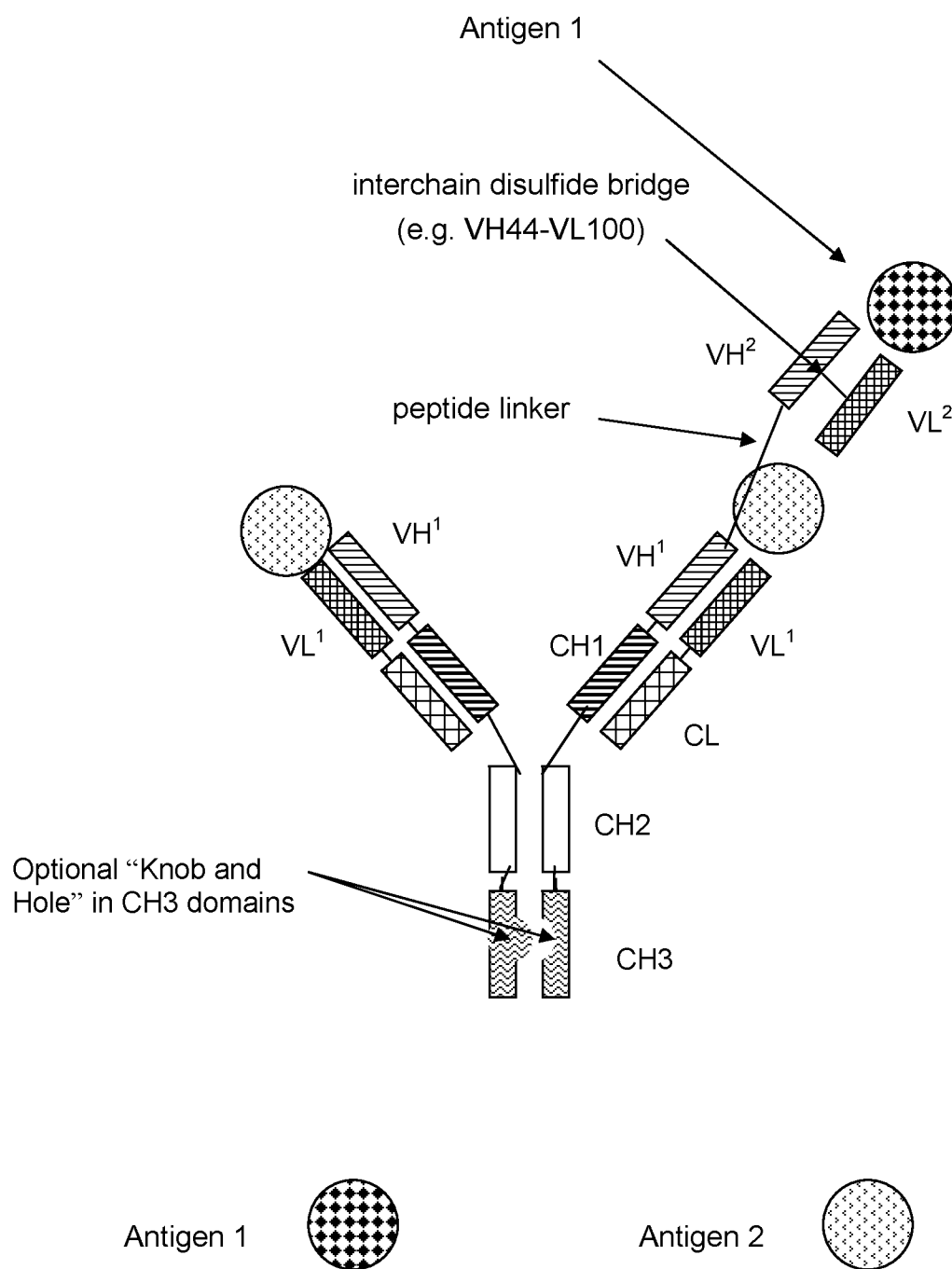


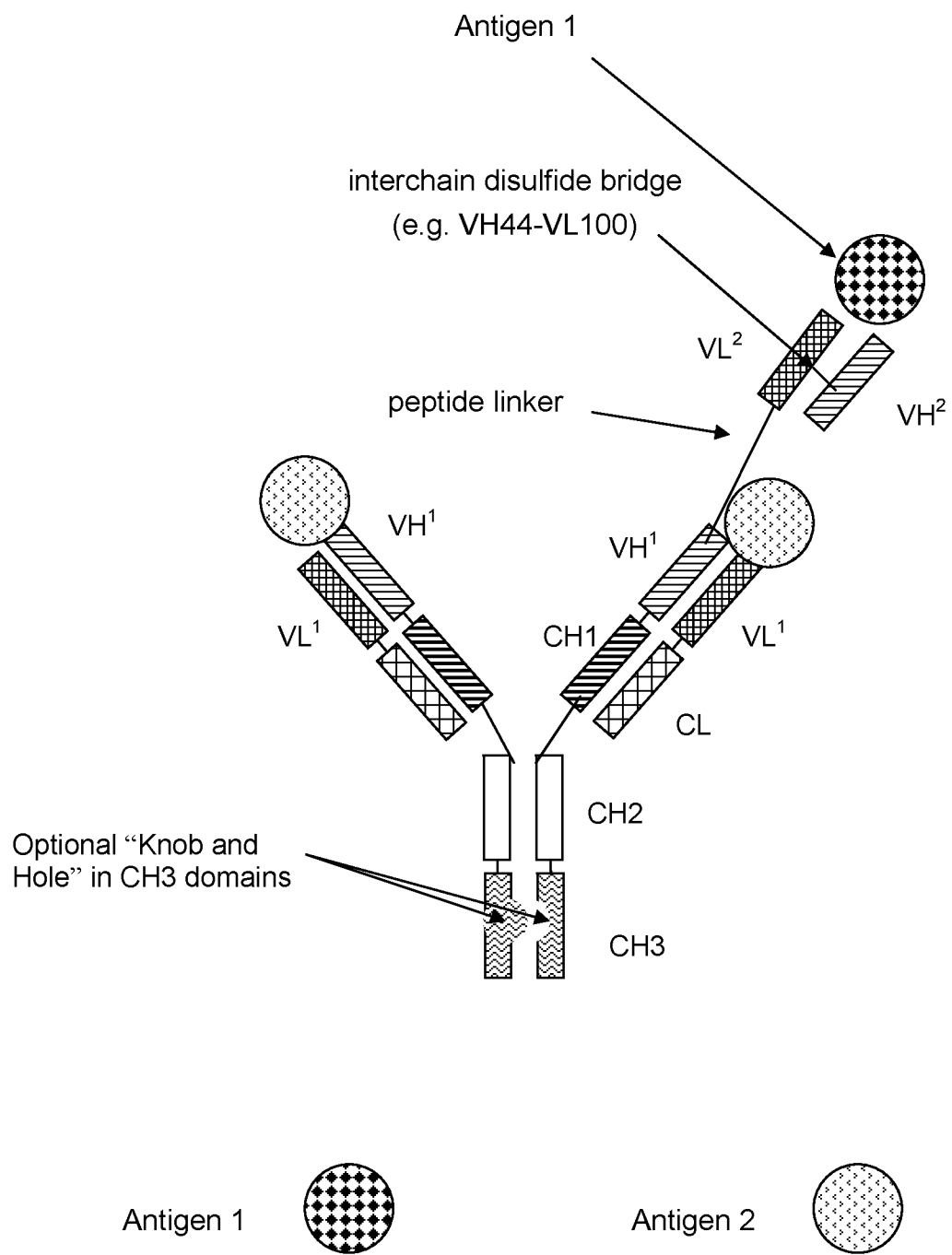
Figure 3e

Figure 4a

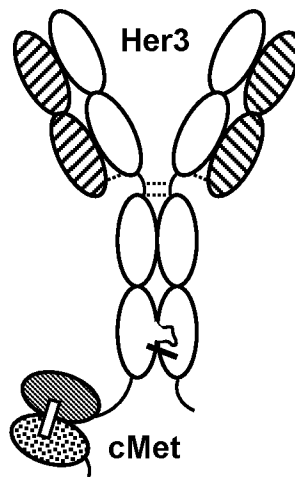


Figure 4b

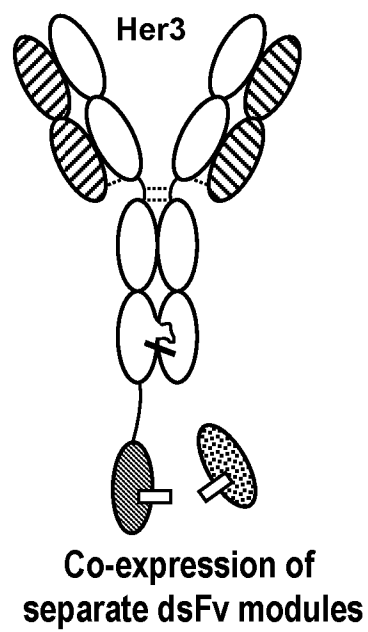


Figure 4c

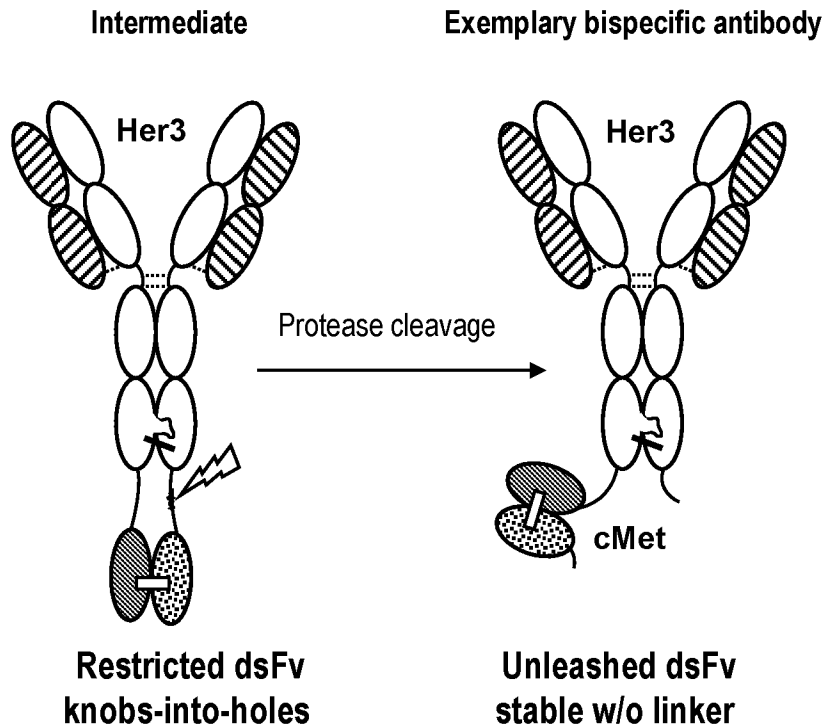
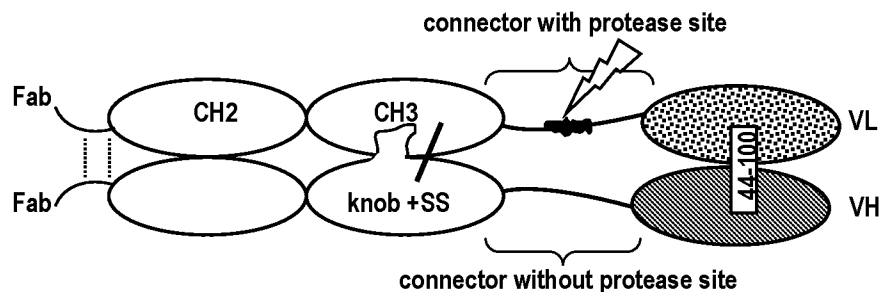


Figure 4d



Connector w/o protease site	CH3 (knob) (GGGS) ² -GGGS GGGS (GGGS) ² V _H cys ₄₄
Prescission recognition site	CH3 (hole) (GGGS) ² -GLEVL FQ GPS (GGGS) ² V _L cys ₁₀₀
Furin recognition site	CH3 (hole) (GGGS) ² -GQSSRHRR AL (GGGS) ² V _L cys ₁₀₀

Figure 5

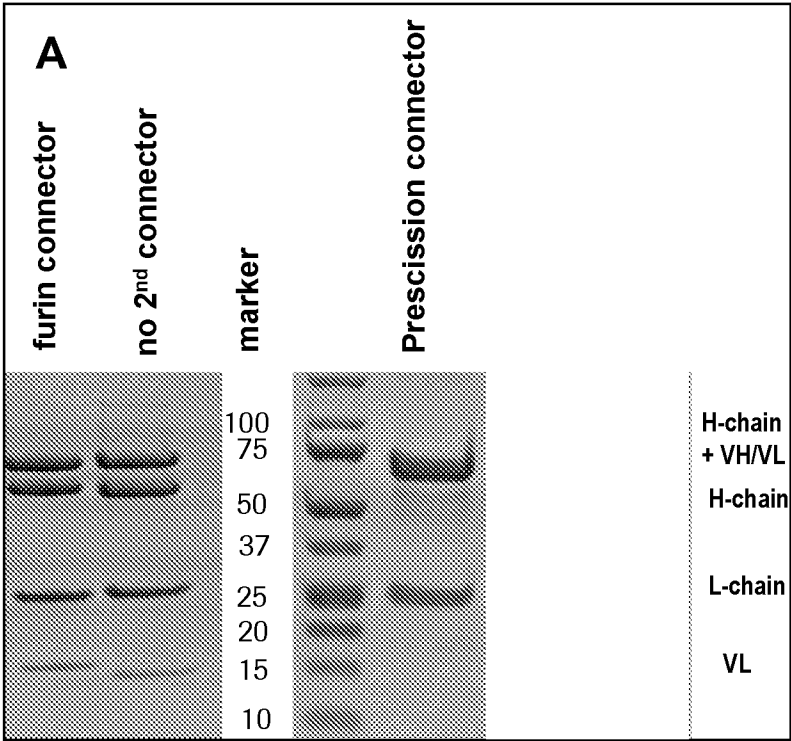


Figure 6

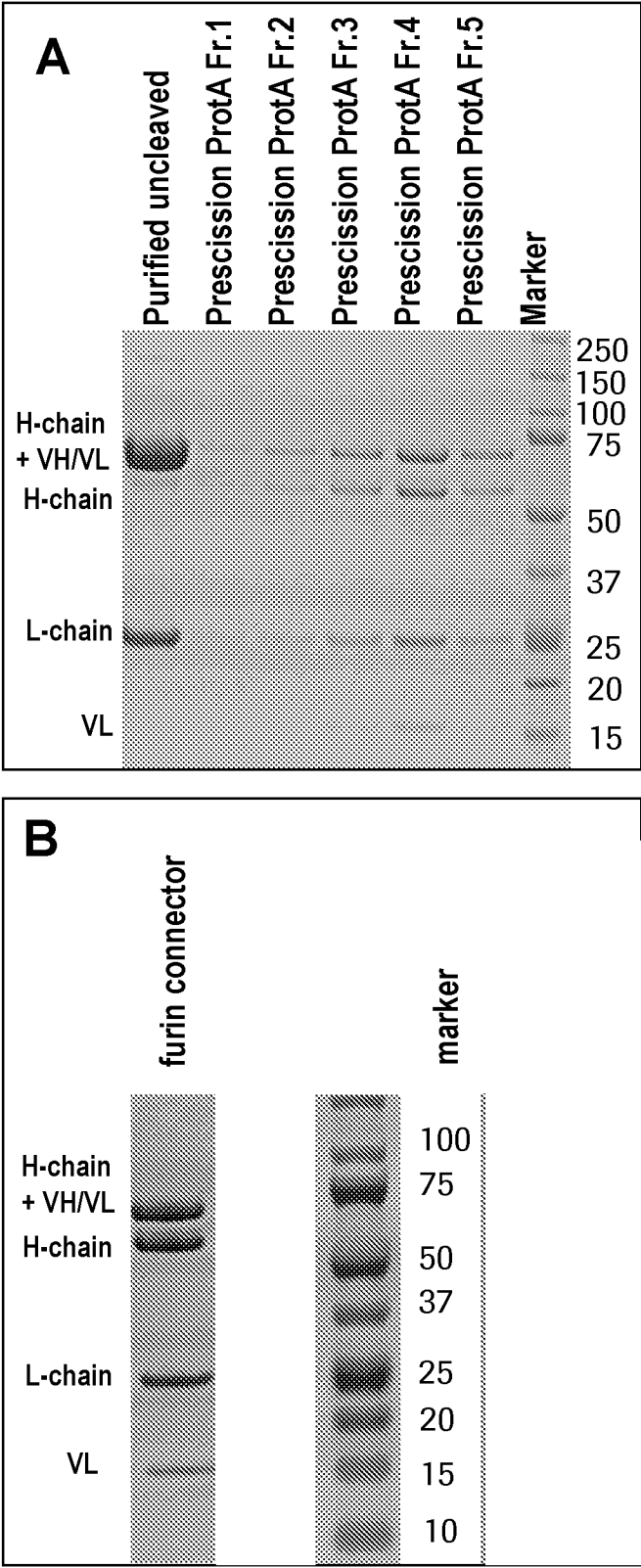


Figure 7

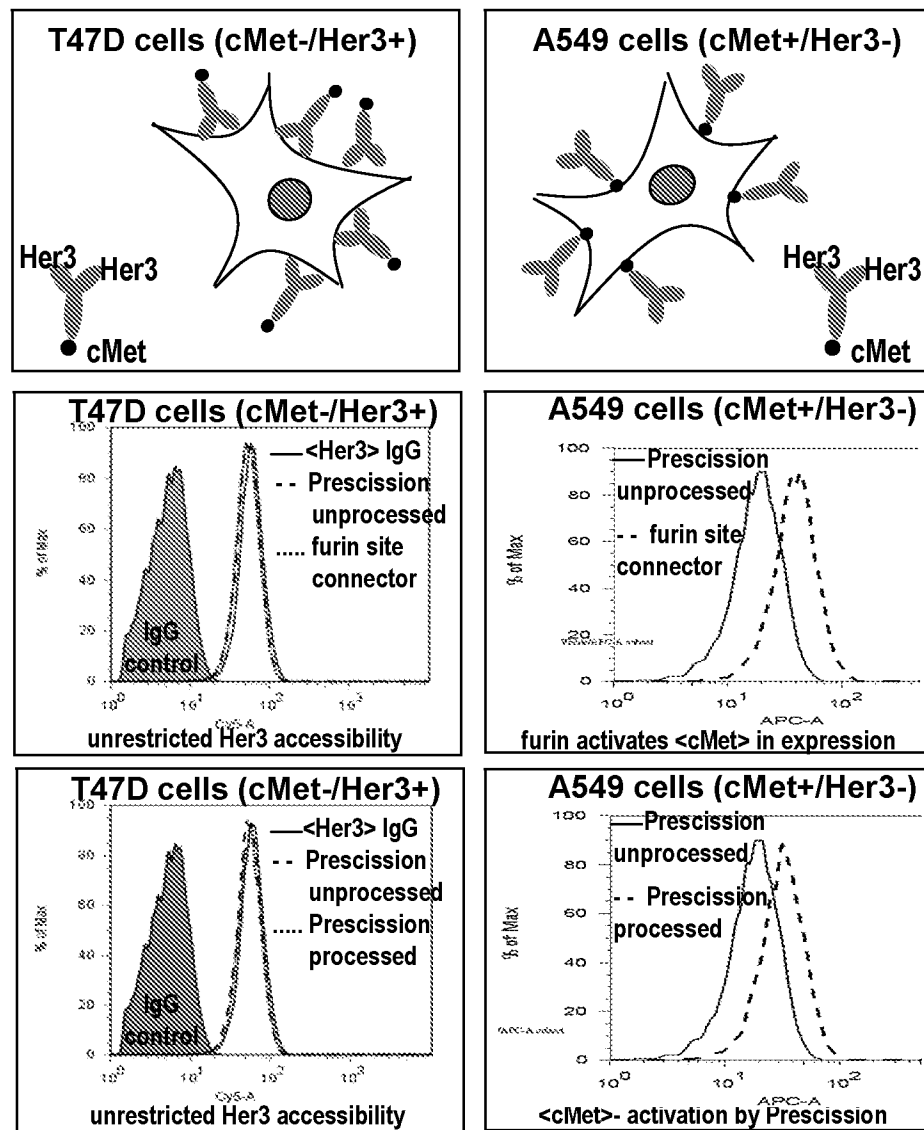


Figure 8A

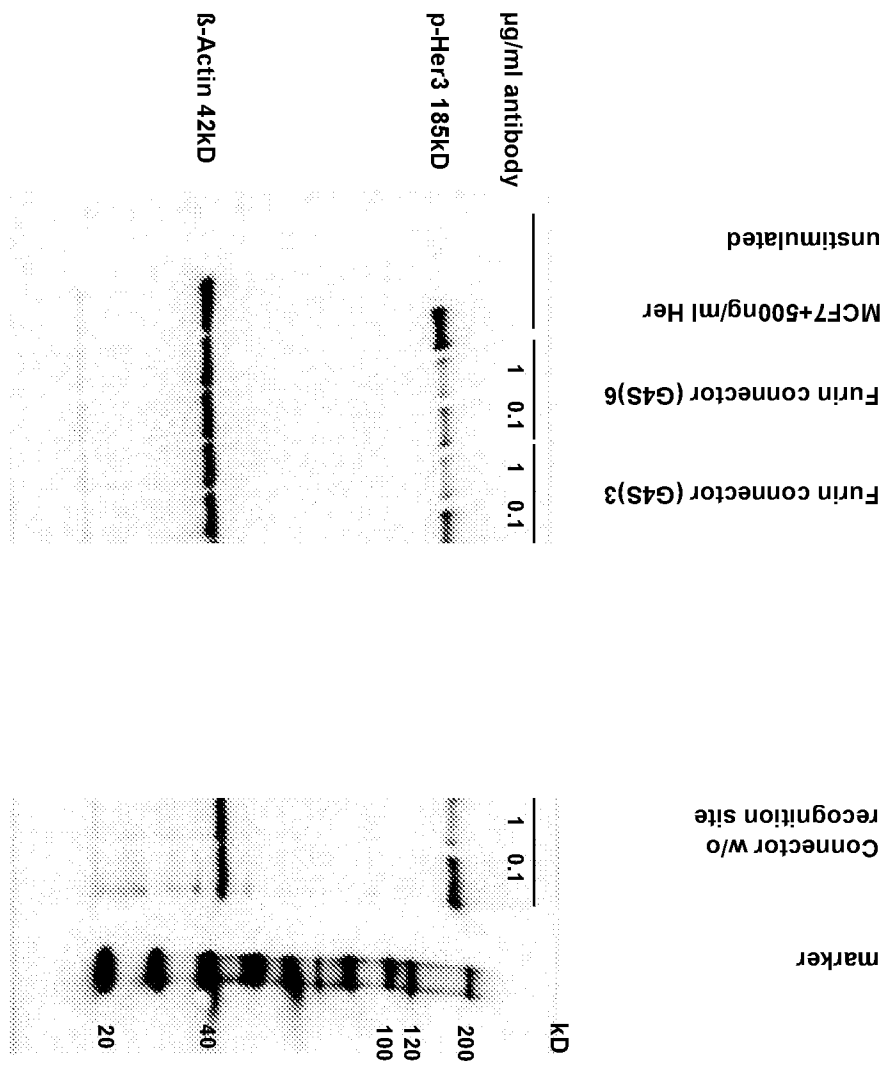


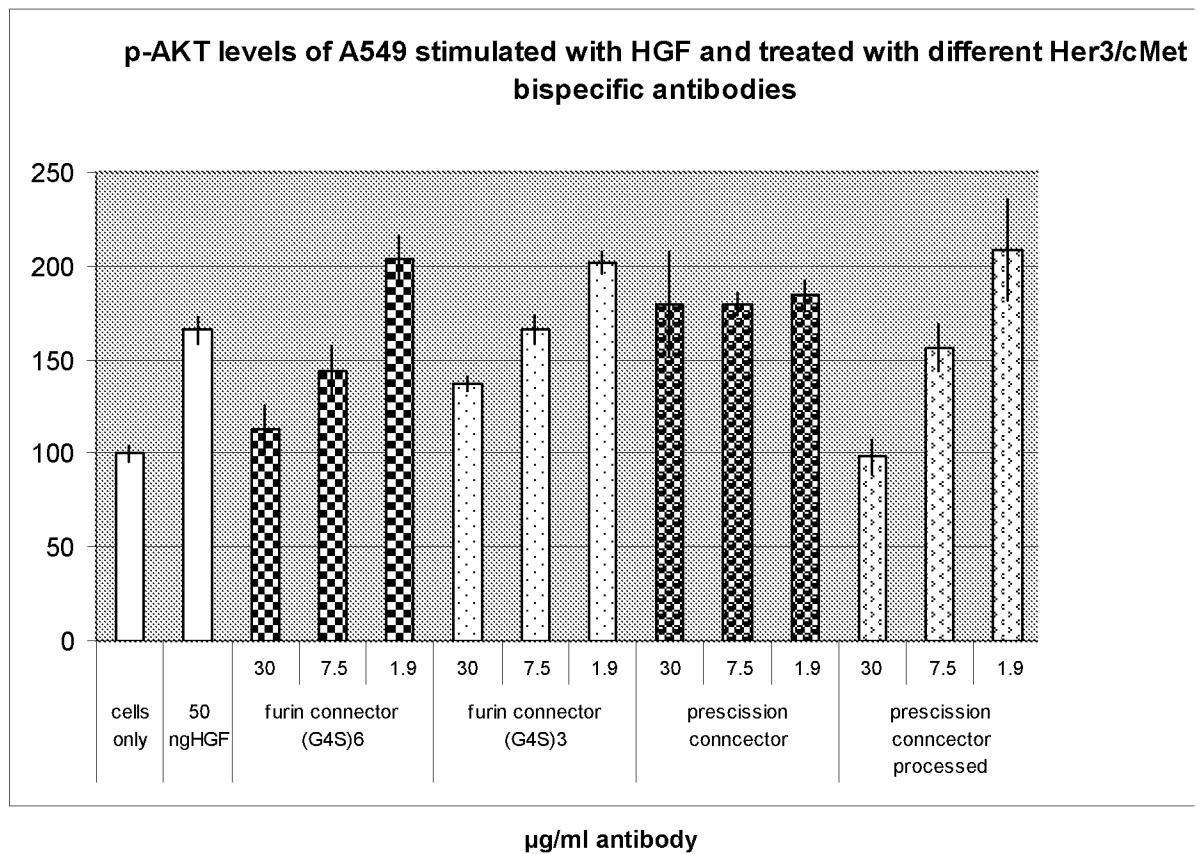
Figure 8B

Figure 9

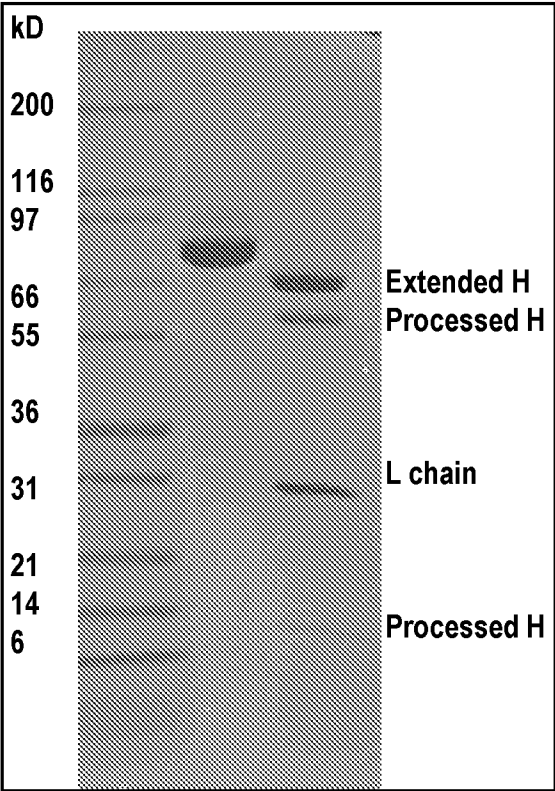


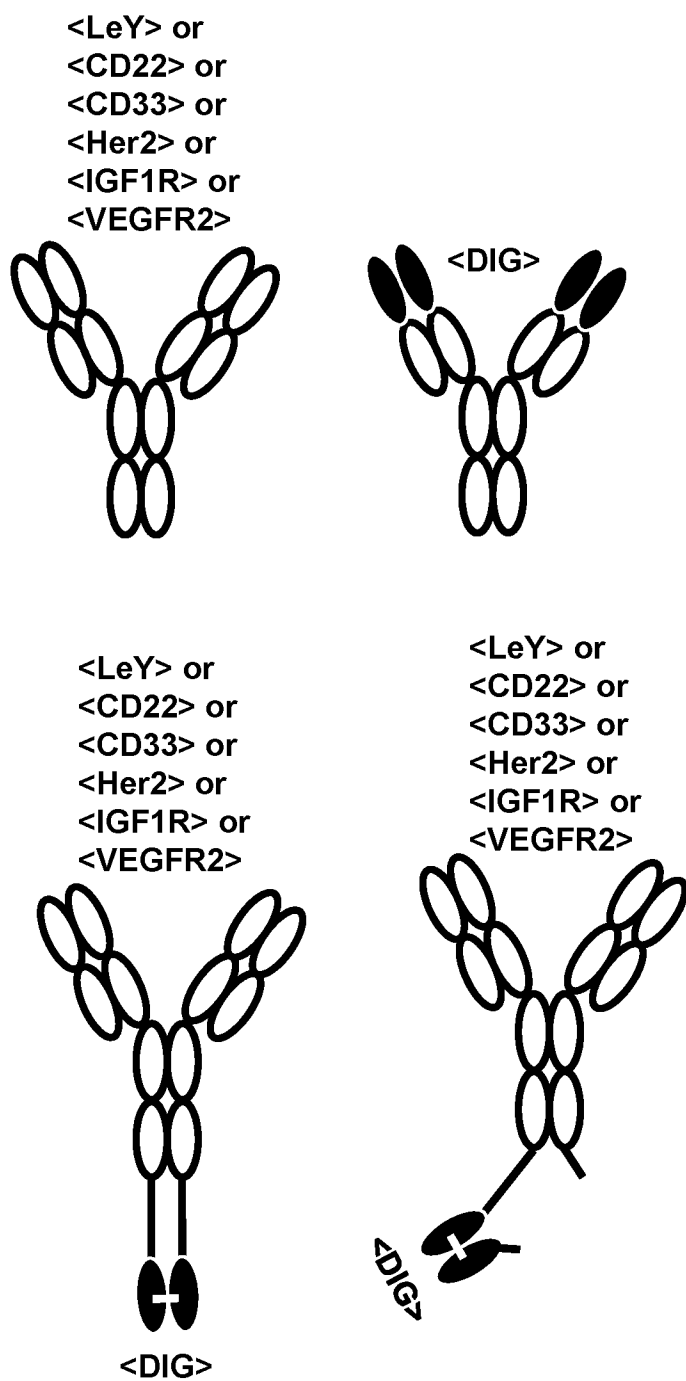
Figure 10

Figure 11a

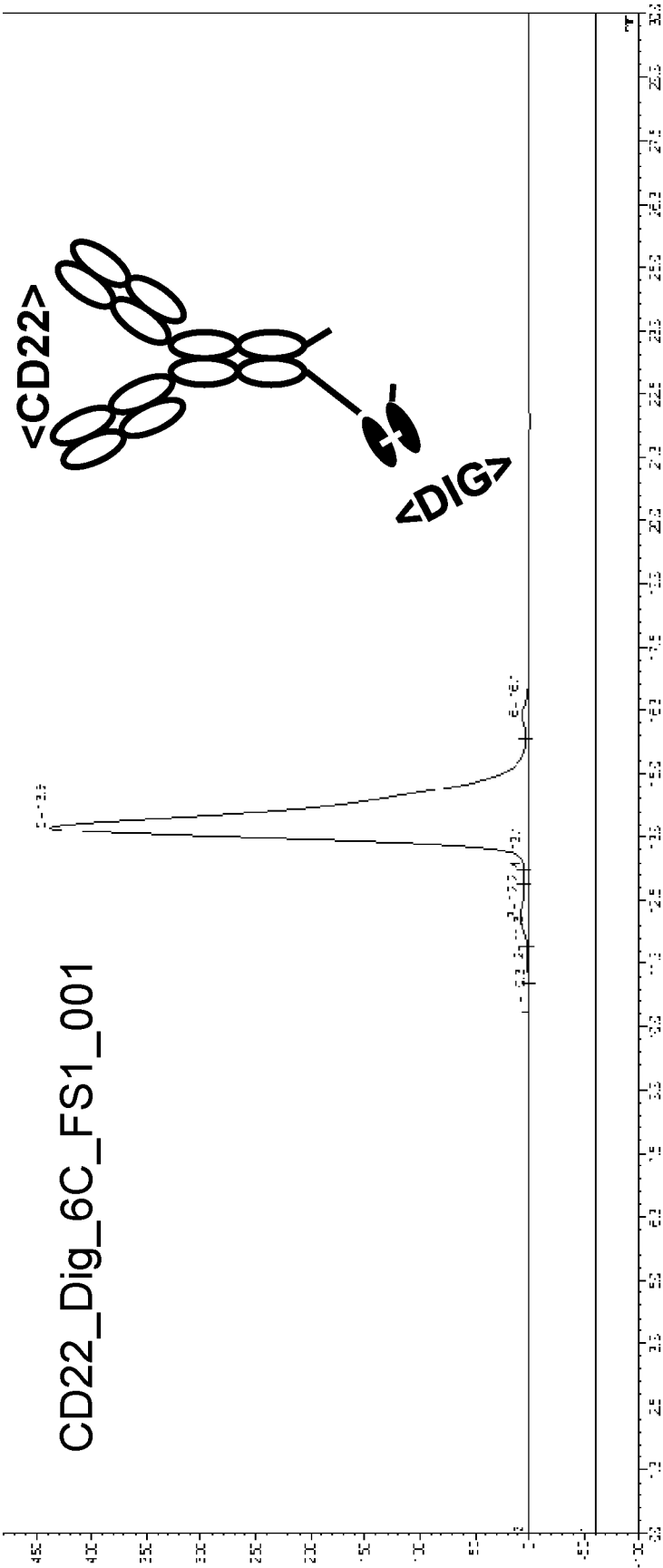


Figure 11b

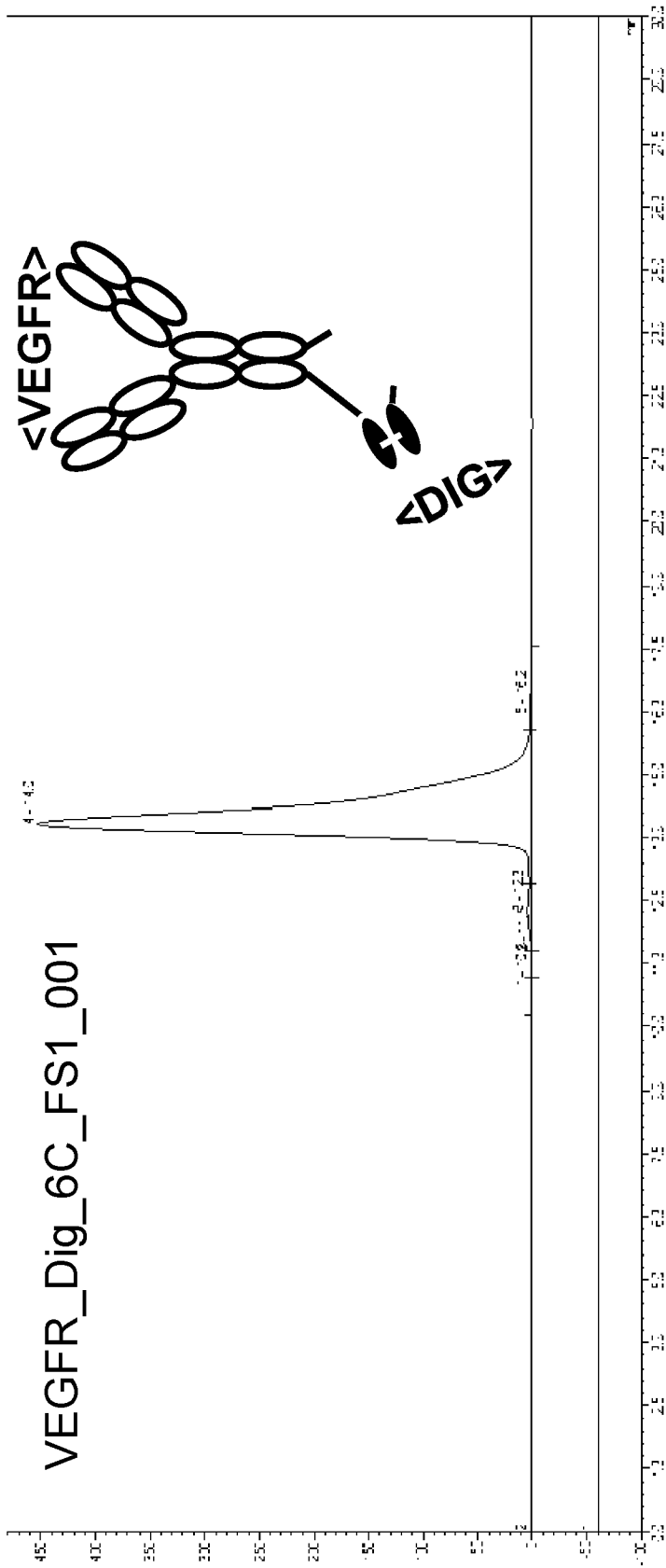


Figure 12

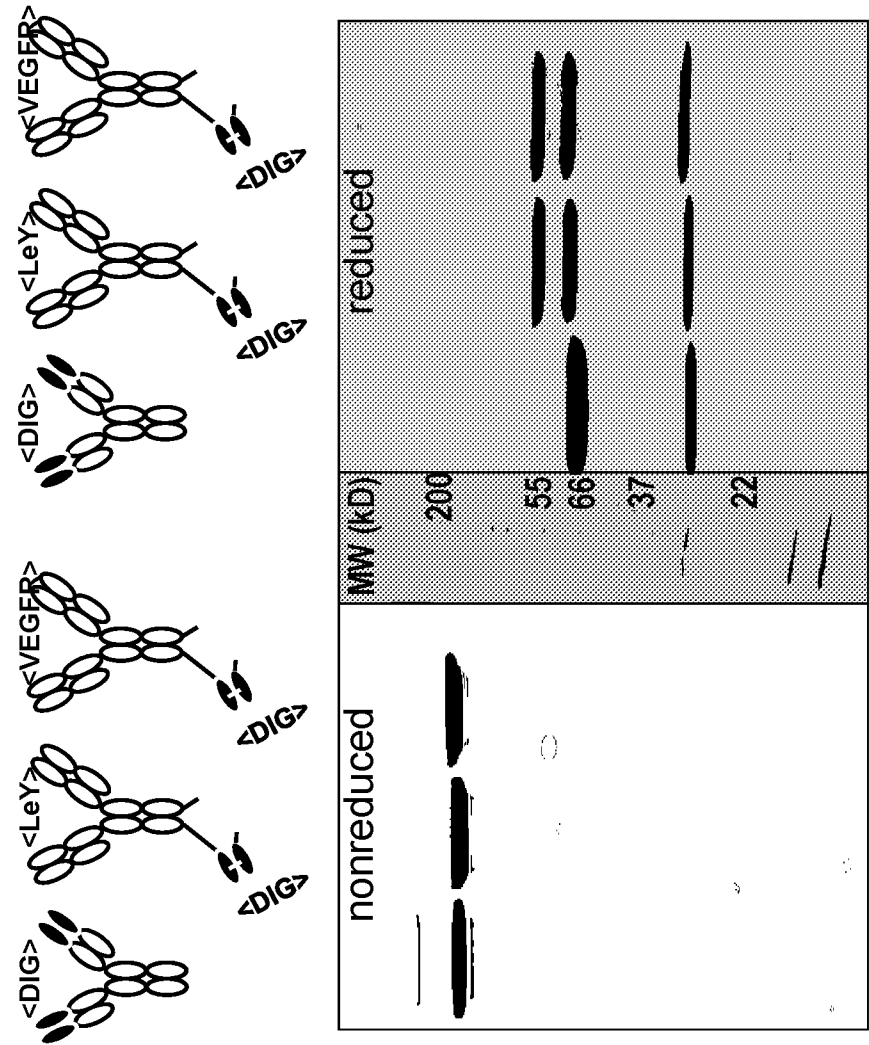


Figure 13a

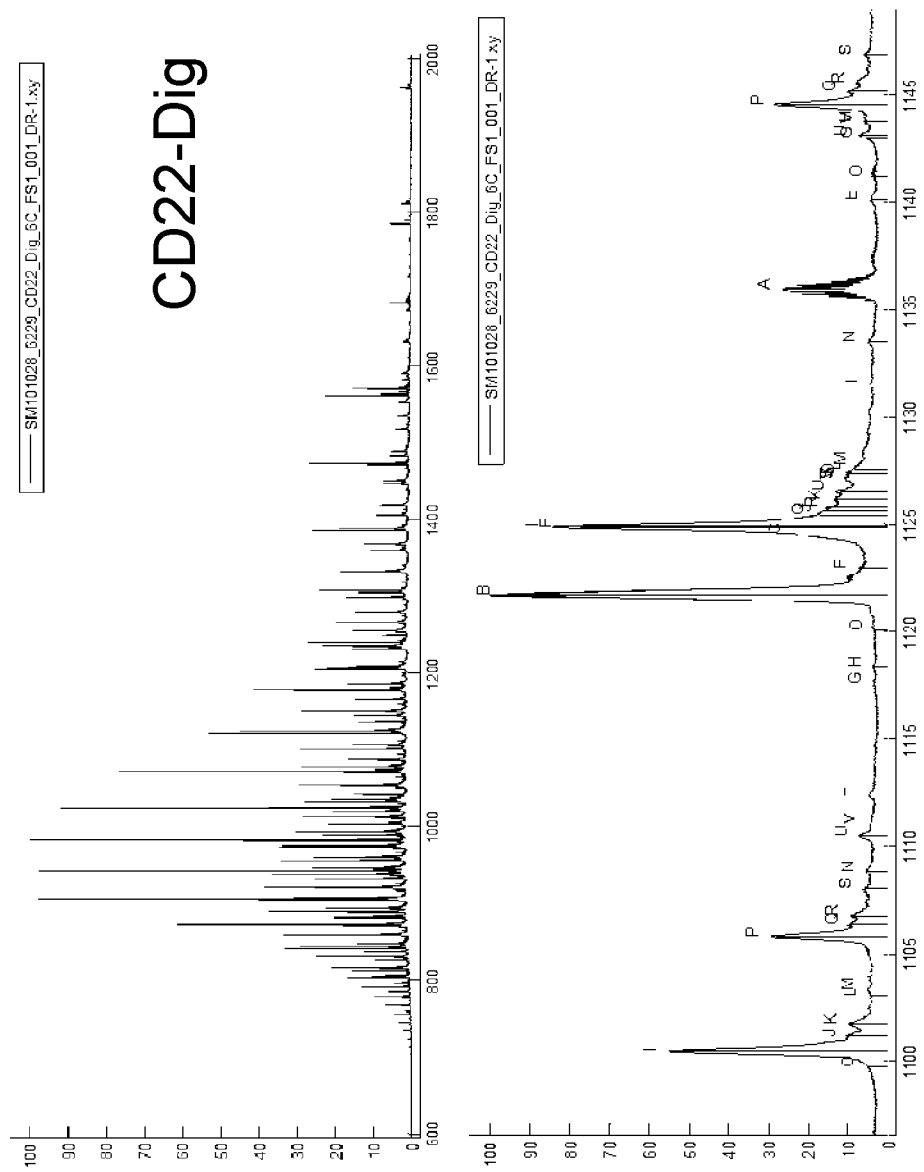


Figure 13b

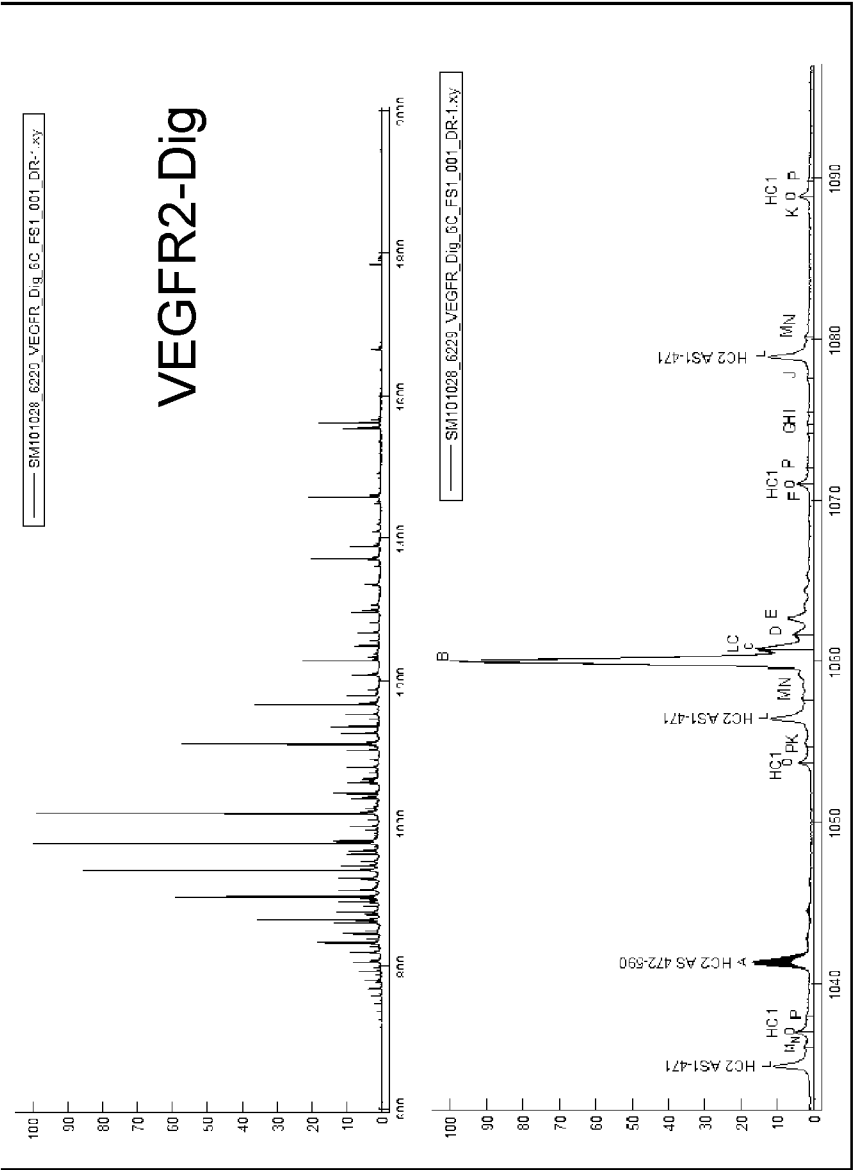


Figure 14a

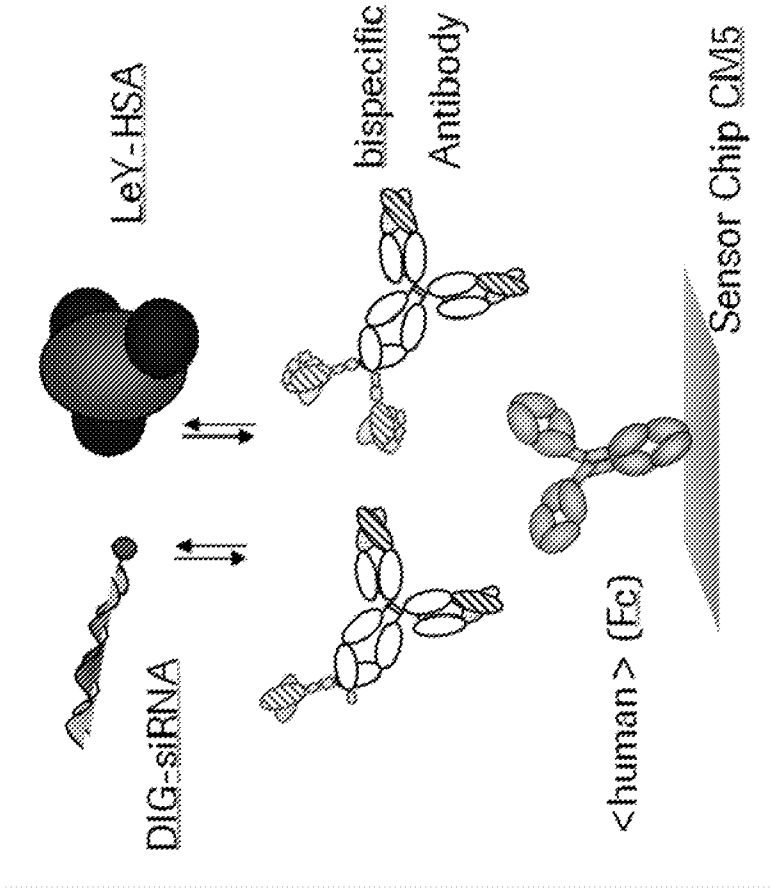


Figure 14b

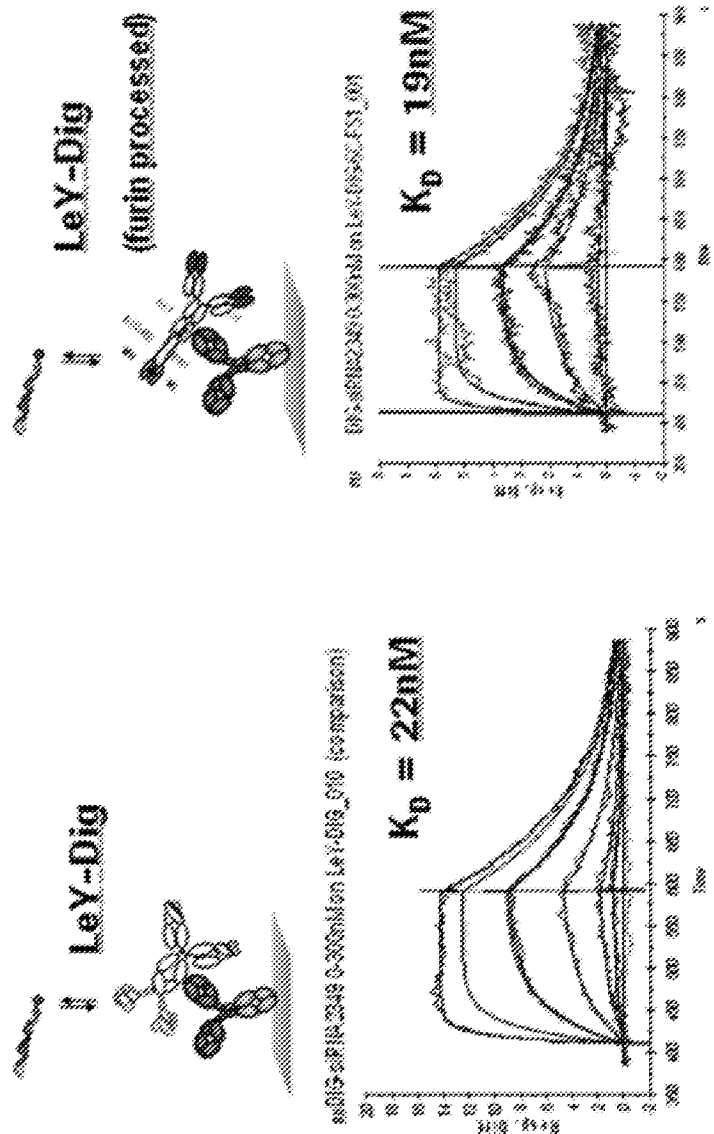


Figure 14c

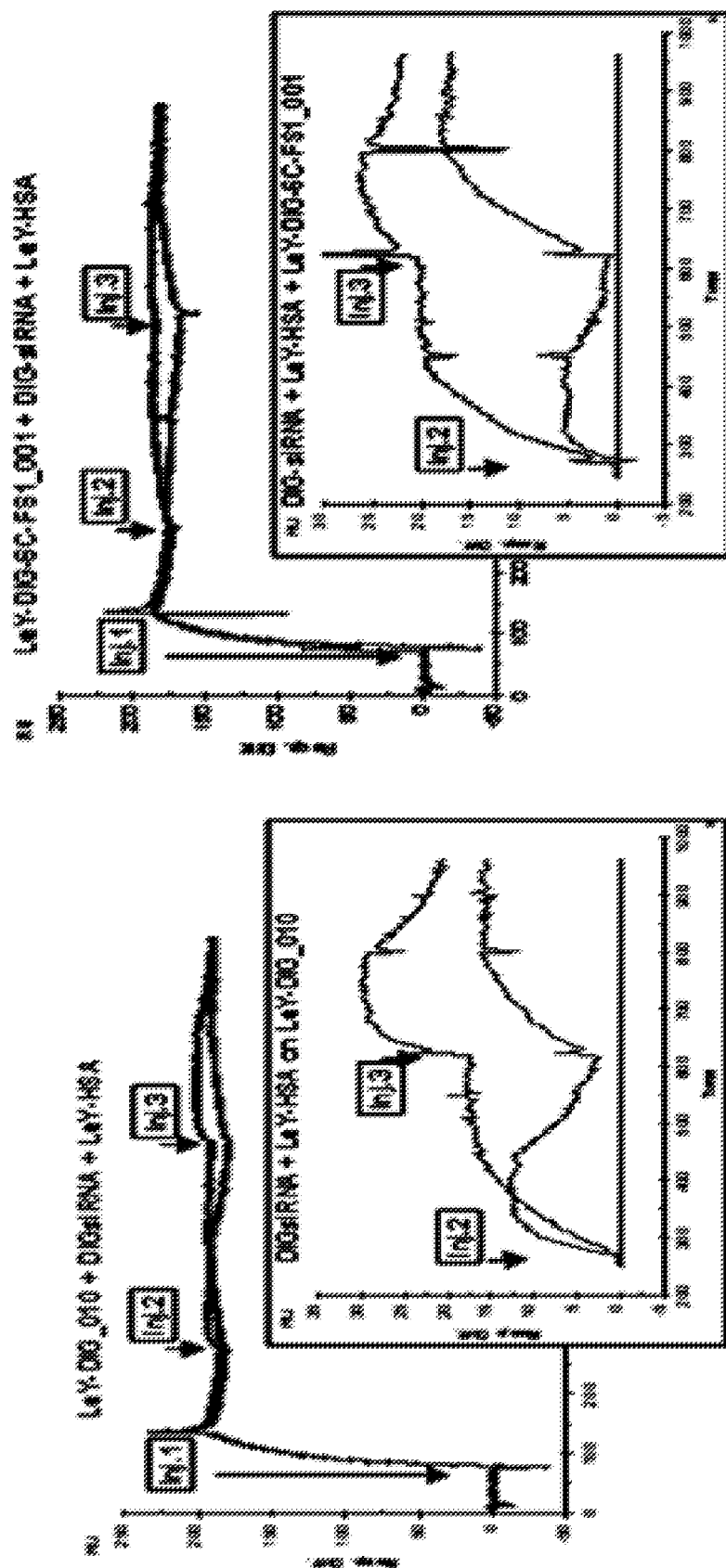


Figure 15a

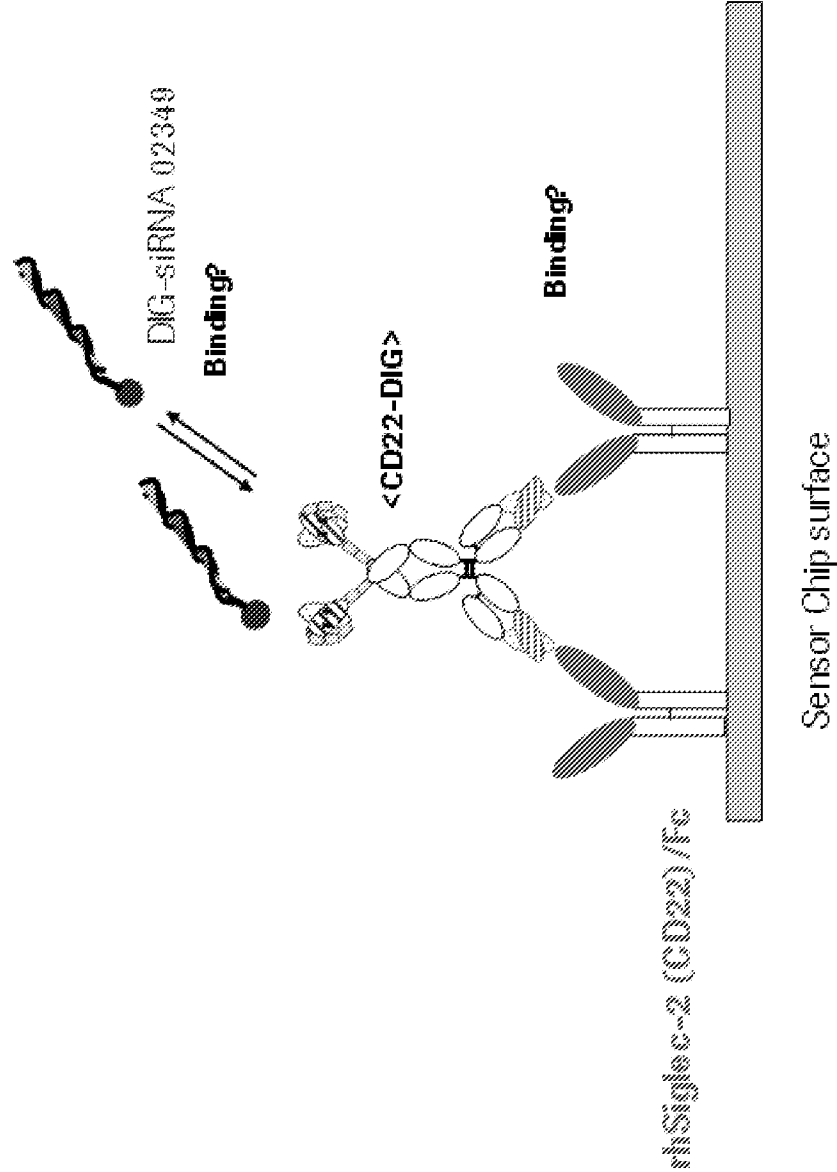


Figure 15b

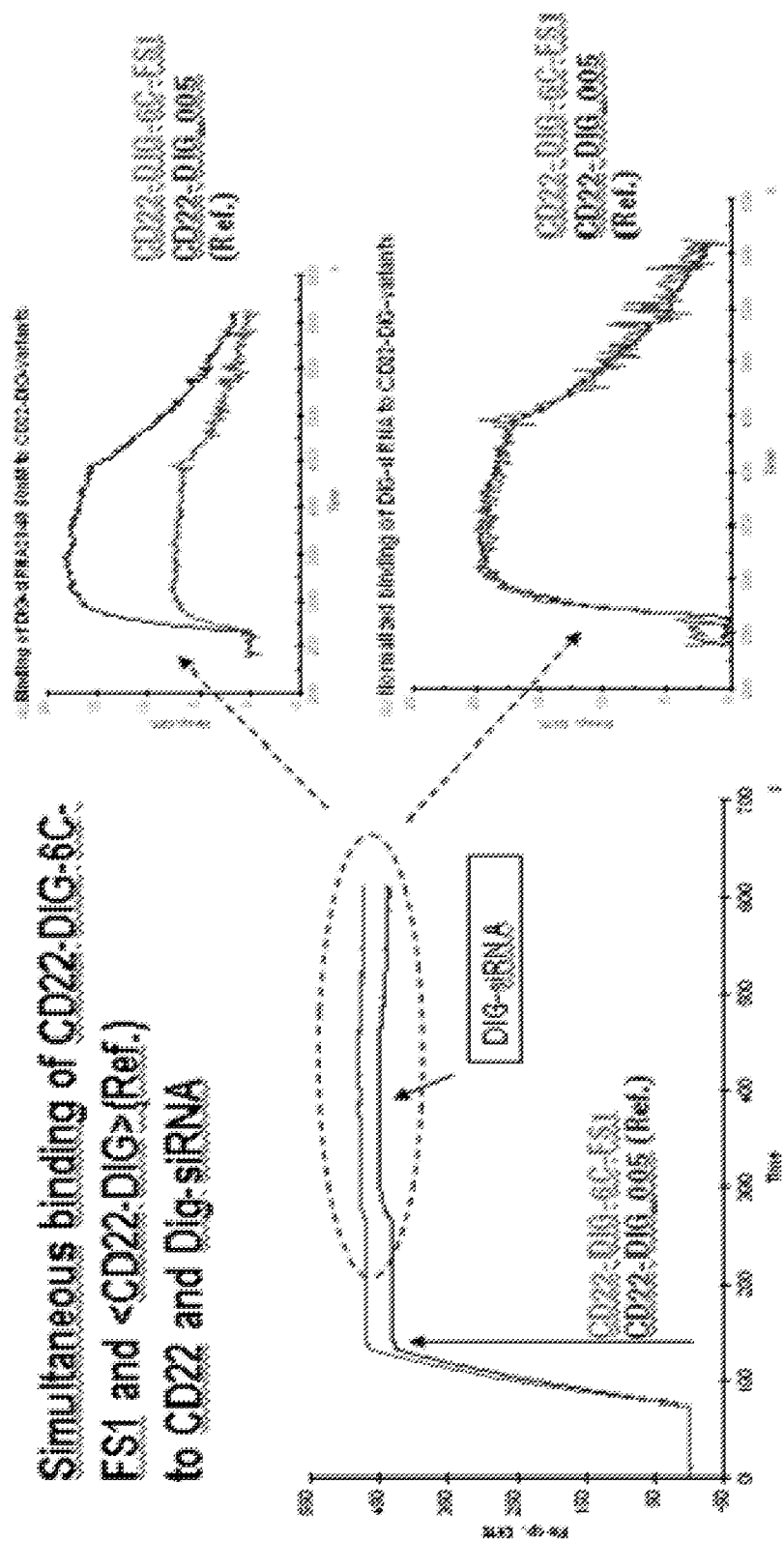


Figure 16a

FACS detection via anti hu Ckappa

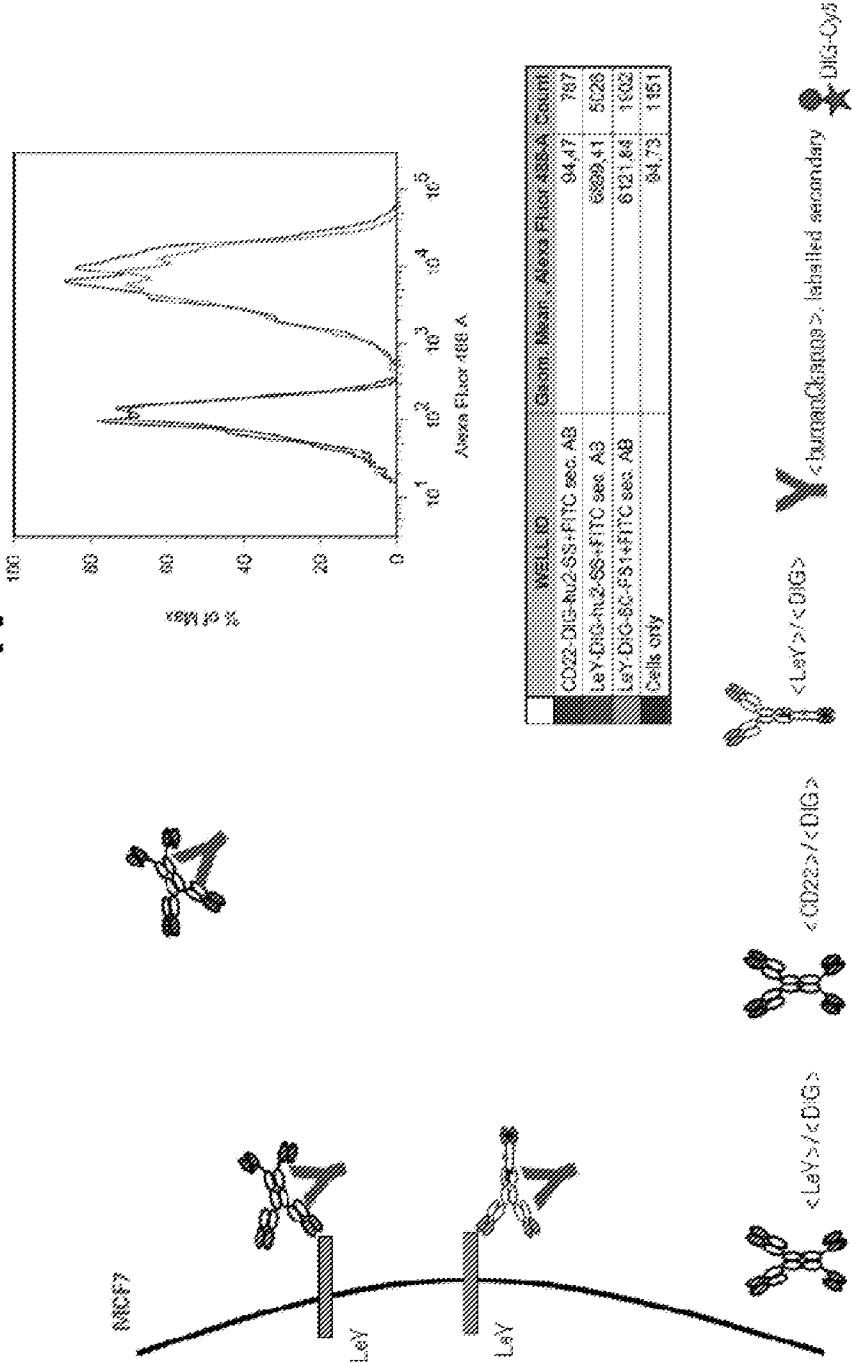
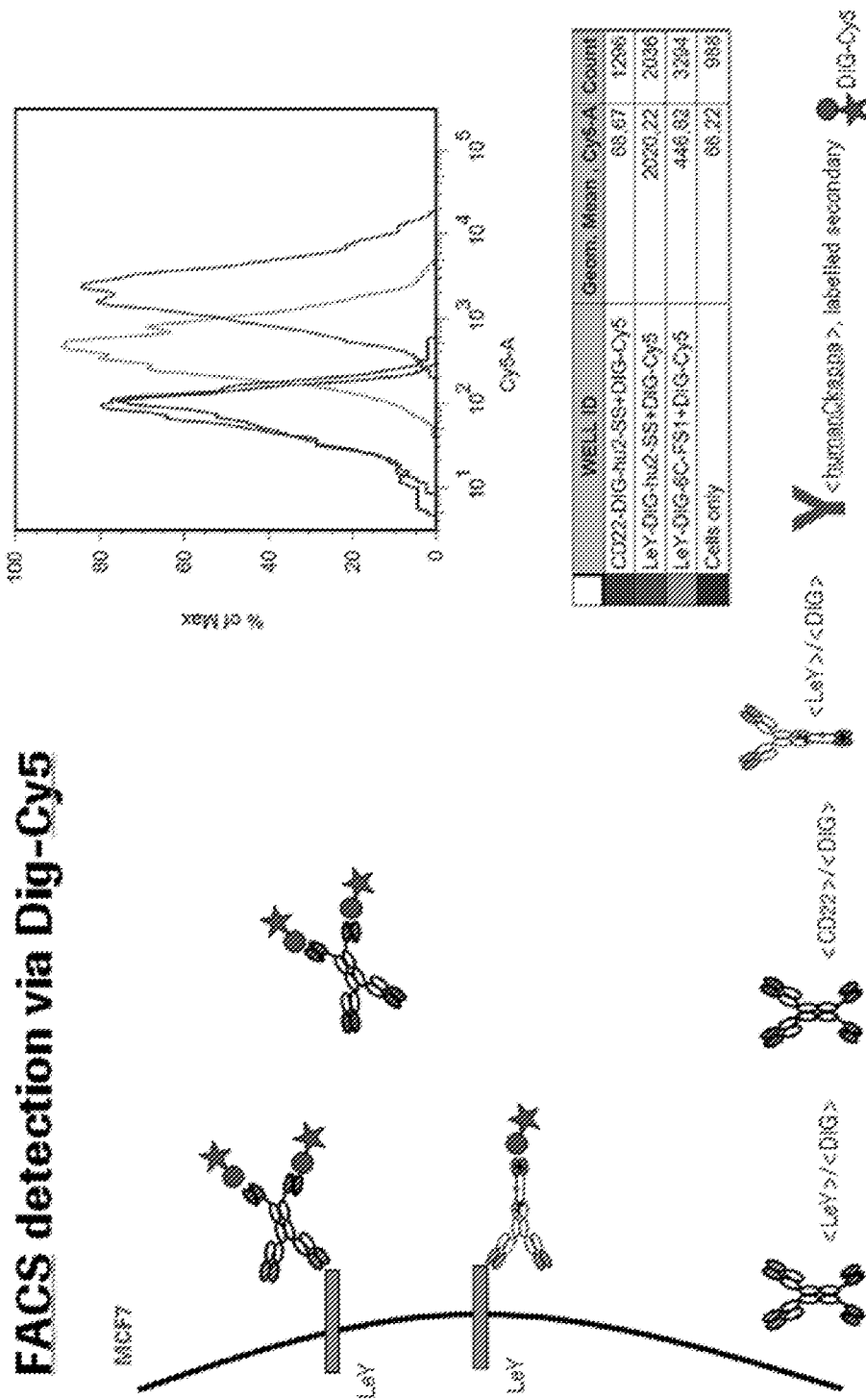


Figure 16b



INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2011/064476

A. CLASSIFICATION OF SUBJECT MATTER

INV. C07K16/00 C07K16/32 C07K16/28
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C07K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, EMBASE, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	"Production in yeasts of stable antibody fragments", EXPERT OPINION ON THERAPEUTIC PATENTS, vol. 7, 1 February 1997 (1997-02-01), page 179-183, XP002623243, DOI: 10.1517/13543776.7.2.179 the whole document ----- -/-	1-18



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

17 November 2011

Date of mailing of the international search report

06/12/2011

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Authorized officer

Lechner, Oskar

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2011/064476

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International application No
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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2011/064476

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International application No

PCT/EP2011/064476

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