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(54) Title: POLYMER

(57) Abstract: The application provides a method of producing a comb polymer comprising the steps of: (a) Providing: (i) a plurality of monomers which are linear, branched or star-shaped, substituted or non-substituted, and have an olefinically unsaturated moiety, the olefinically unsaturated moiety being capable of undergoing addition polymerisation; (ii) an initiator compound; the initiator compound comprising a homolytically cleavable bond. (iii) a catalyst capable of catalysing the polymerisation of the monomer; and (b) Causing the catalyst to catalyse, in combination with the initiator, the polymerisation of a plurality of the monomers to produce the comb polymer Catalysts and polymers obtainable by the process are also provided. Preferably, the comb polymer is capable of binding proteins and may be produced from monomers which are alkoxy polyethers, such as poly(alkyleneglycol) or polytetrahydrofuran.

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Polymer

The invention relates to processes of making comb polymers from monomers comprising alkoxy polyethers, such as polyalkylene glycol such as poly (ethylene glycol), or polytetrahydrofuran (PTHF). Such methods may include the use of an initiator compound which comprises a moiety which, when attached to the comb polymer, is capable of binding to a protein or polypeptide. The initiator compounds and finished comb polymers, and their uses, are also included within the invention.

The modification of proteins with polymers such as poly (ethylene glycol), which is known by the abbreviation PEG, is well-known in the art. PEG-derivatives are manufactured, for example, by Shearwater Corporation, Huntsville, AL., USA, and Enzon, Inc., Bridgewater, NJ., USA. Uses of PEG are reviewed in catalogues from both of those companies, and indeed in the 2002 Enzon, Inc. Annual Report.

The attachment of PEG to proteins or polypeptides, known as PEGylation has been found to have a number of benefits. Firstly, this reduces the antigenicity and immunogenicity of a molecule to which PEG is attached. PEG also produces markedly improved circulating half-lives *in vivo* due to either evasion of renal clearance as a result of the polymer increasing the apparent size of the molecule to above the glomerular filtration limit, and/or through evasion of cellular clearance mechanisms. PEG can markedly improve the solubility of proteins and polypeptides to which it is attached, for example PEG has been found to be soluble in many different solvents, ranging from water to many organic solvents such as toluene, methylene chloride, ethanol and acetone. An application of this has been to use PEG-modified antibodies, for example to phase partition target molecules or cells. PEGylation has also been found to enhance proteolytic resistance of the conjugated protein, and improve bioavailability via reduced losses at subcutaneous injection sites. PEGylation also has been observed to reduce the toxicity of the proteins or polypeptides to which it is attached, improve thermal and mechanical stability of the molecules and allow the improved formulation into materials used for some slow release administration strategies. These advantages are reviewed in, for example, the articles by Chapman A.P. (Advanced Drug Delivery Reviews, Vol. 54 (2002), pages 531-545). The

chemistry of polypeptide and protein PEGylation is further reviewed in the article by Roberts, M.J., *et al.* (Advanced Drug Delivery Reviews, Vol. 54 (2002), pages 459-476), and the article by Kinstler, O., *et al.* (Advanced Drug Delivery Reviews, Vol. 54 (2002), pages 477-485).

A number of PEGylated drugs are on the market. For example, PEG-INTRON™ is an α -interferon product produced by Schering-Plough and Enzon, Inc. which is used to treat hepatitis C and cancer. Prothecan™ is a PEG-enhanced version of camptothecin, a topoisomerase I inhibitor that is effective against some cancers. PEGylated taxol and several enzyme-based products have also been produced which show, for example, better uptake in tumours and reduced side-effects compared to non-PEGylated compounds. As discussed in the review by Roberts (Supra), polymers such as PEG may be attached via a number of reactive amino acids on protein or polypeptide molecules, including lysine, cysteine, histidine, arginine, aspartic acid, glutamic acid, serine, threonine, tyrosine, N-terminal amino groups and C-terminal carboxylic acid groups. In the case of glycoproteins, vicinal hydroxyl groups can be oxidised with periodate to form two reactive formyl moieties. A wide range of functional groups may be attached to compounds such as PEG to allow them to attach to lysine amine groups and N-terminal amine groups. These include succinimidyl succinate, hydroxysuccinamide and hydroxysuccinamide esters, aldehyde derivatives such as propionaldehyde and acetaldehyde, propionate and butanoate derivatives of succinimidyl, benzotriazole carbonate, *p*-nitrophenyl carbonate, trichlorophenyl carbonate and carbonylimidazole. Compounds such as tresylate are known to bind to proteins via nucleophilic attack. There are also a number of compounds which can react with cysteine residues on proteins or polypeptides. These include maleimides, vinylsulphones, pyridyl sulphides and iodoacetamides. Furthermore, succinimidyl carbonate can also be used as a functionalised group to attach PEG or other polymers to alanine or histidine amino acids within a protein or polypeptide. As already indicated, the reaction of such functionalised groups is already well-characterised as indicated in the articles by Roberts, Kinsler and Chapman, and indeed as shown in, for example, the Shearwater Catalogue (2001).

The PEG currently on the market is usually in the form of long poly (ethylene glycol) polymers or branched or star-shaped poly (ethylene glycols).

The Applicants have now identified that it is possible to produce comb polymers which allow the size of the polymer attached to biological substances, for example, proteins and polypeptides, nucleic acids (DNA and RNA), carbohydrates and fats, to be varied and to be controlled. This allows the possibility of producing a wide variety of different polymers for attaching to proteins and polypeptides, which may be varied in their size and hydrodynamic volume to vary the properties of the compound to which the polymer is attached. For example, this may be used to vary the stability, solubility, toxicity and/or drug retention time of a drug which has been covalently attached to such co-polymers. Such co-polymers are capable of being produced in a controlled manner by so-called living radical polymerisation.

Living radical polymerisation is subject of International Patent Application No. WO 97/47661. Supported polymerisation catalysts and specific polymerisation initiators are also shown in WO 99/28352 and WO 01/94424. Basically, the system uses a compound complexed with a transition metal. This compound is preferably an organodiimine, although one of the nitrogens of the diimine is preferably not part of an aromatic ring (e.g. a 1,4-diaza-1,3-butadiene, a 2-pyridinecarbaldehyde imine, an oxazolidone or a quinoline carbaldehyde).

Living free radical systems, which involve the use of free radical initiators are also known, see for example WO 96/30421 and WO 97/18247. This is reviewed in Kamigaito, *et al.*, Chem. Rev. (2001), Vol. 12, pages 3689-3745.

A combination of the catalyst and the initiators has in the past been used to polymerise olefinically un-saturated monomers, such as vinylic monomers. The inventors have now realised that these systems may be used to produce comb polymers in a controlled manner. These comb polymers may have a functional group attached to them via conventional chemistry. However, the inventors have also realised that the initiators used in living radical polymerisation are attached to the comb polymer as a result of the reaction of the

initiator with the monomers. This means that it is possible to functionalise the comb polymer at the same time as producing the co-polymer, by using a functionalised initiator.

Accordingly, the first aspect of the invention provides a method of producing a comb polymer comprising the steps of:

- (a) Providing:
 - (i) a plurality of monomers which are linear, branched or star-shaped, substituted or non-substituted, preferably containing 2, especially from 3 to 10, carbon atoms, and have an olefinically unsaturated moiety attached thereto, the olefinically unsaturated moiety being capable of undergoing addition polymerisation;
 - (ii) an initiator compound; the initiator compound comprising a homolytically cleavable bond;
 - (iii) a catalyst capable of catalysing the polymerisation of the monomers; and
- (b) Causing the catalyst to catalyse, in combination with the initiator, the polymerisation of a plurality of the monomers to produce the comb polymer;

wherein the initiator compound (ii) comprises a moiety which, when attached to the comb polymer, is capable of binding to a biological substance.

The monomers in (i) are preferably alkoxy polyethers such as poly (alkylene glycol) or polytetrahydrofuran.

The comb polymer may have a moiety which, when attached to the comb polymer, is capable of binding e.g. a protein or polypeptide, attached to it using conventional chemistry. However, as already indicated, it is possible to produce initiator compounds which have that moiety attached to them. Therefore, preferably the initiator compound comprises a moiety which, when attached to a comb polymer, is capable of binding to a biological substance, such as a protein or polypeptide, nucleic acid (DNA or RNA), carbohydrates or fats.

Preferably, the poly (alkylene glycol) is a polymer of an alkylene glycol containing from 2-10, especially at least 3, carbon atoms, most preferably poly (ethylene glycol), poly (propylene glycol) or poly (butylene glycol). For example, poly (ethylene glycol) may be used.

In its most common form, this is a linear or branched polyether terminated with hydroxyl groups. This is synthesised by anionic ring opening polymerisation of ethylene oxide initiated by nucleophilic attack of a hydroxide ion on the epoxide ring. It is also possible to modify polyethylene glycol, for example by placing a monomethoxy group on one end to produce monomethoxy PEG (mPEG). This is synthesised by an ionic ring opening polymerisation initiated with methoxide ions and is commercially available. However, trace amounts of water present in the reaction mixture causes the production of significant quantities of PEG which is terminated at both ends by hydroxy groups. This is undesirable, as the moiety capable of binding to proteins or peptides will then attach to both ends of the polymer chain, which will cause unwanted cross-linking of proteins in the body.

A method intended to minimise the production of this impurity is to initiate the ring opening of ethylene oxide by nucleophilic attack of a benzoxy ion on the epoxide ring. In a similar manner to the above process, monobenzoxy PEG is produced, as well as the PEG chain terminated at both ends by hydroxy. This mixture is methylated, producing one chain terminated with BzO and OMe, and dimethoxy PEG. Hydrogenation of this mixture eliminates the benzoxy group to yield mPEG and dimethoxy PEG. Dimethoxy PEG remains present as an inert impurity. However, even using this process, the product obtained still contains 5-10% of the unwanted dihydroxy PEG according to its certificate of analysis.

The process of the present invention yields a product which is substantially 100% pure, eliminating substantially all of the dihydroxy PEG impurity, thus avoiding the disadvantages of the known processes, and removing the possibility of the cross-linking of proteins.

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Branched and star-shaped polymers such as PEG are available from a number of commercial sources, such as Enzon and Shearwater. Polytetrahydrofurans may also be obtained from commercial sources, such as Aldrich (Gillingham, Dorset, UK.).

Preferably, the molecular weight of the PEGmethacrylate is 475, 1100, 2080, 5000 or 20,000.

The polyalkylene glycol and polytetrahydrofuran comprises an olefinically unsaturated moiety, for example at the end of the polymer chain. This olefinically unsaturated moiety is capable of undergoing additional polymerisation.

The olefinically unsaturated monomer may be a methacrylate, an acrylate, a styrene, methacrylonitrile or a diene such as butadiene.

Examples of olefinically unsaturated moieties that may be used include methyl methacrylate, ethyl methacrylate, propyl methacrylate (all isomers), butyl methacrylate (all isomers), and other alkyl methacrylates; corresponding acrylates; also functionalised methacrylates and acrylates including glycidyl methacrylate, trimethoxysilyl propyl methacrylate, allyl methacrylate, hydroxyethyl methacrylate, hydroxypropyl methacrylate, dialkylaminoalkyl methacrylates such as dimethylethylamino methacrylate; fluoroalkyl (meth)acrylates; methacrylic acid, acrylic acid; fumaric acid (and esters), itaconic acid (and esters), maleic anhydride; styrene, α -methyl styrene; vinyl halides such as vinyl chloride and vinyl fluoride; acrylonitrile, methacrylonitrile; glycerol; vinylidene halides of formula $\text{CH}_2 = \text{C}(\text{Hal})_2$ where each halogen is independently Cl or F; optionally substituted butadienes of the formula $\text{CH}_2 = \text{C}(\text{R}^{15}) \text{C}(\text{R}^{15}) = \text{CH}_2$ where R^{15} is independently H, Cl to C10 alkyl, Cl, or F; sulphonic acids or derivatives thereof of formula $\text{CH}_2 = \text{CHSO}_2\text{OM}$ wherein M is Na, K, Li, $\text{N}(\text{R}^{16})_4$ where each R^{16} is independently H or C₁ to C₁₀ alkyl, COZ, ON, $\text{N}(\text{R}^{16})_2$ or SO_2OZ and Z is H, Li, Na, K or $\text{N}(\text{R}^{16})_4$; acrylamide or derivatives thereof of formula $\text{CH}_2 = \text{CHCON}(\text{R}^{16})_2$ and methacrylamide or derivative thereof of formula $\text{CH}_2 = \text{C}(\text{CH}_3)\text{CON}(\text{R}^{16})_2$.

Mixtures of such monomers may be used.

Such unsaturated moieties may be attached, for example, at an end of the polymer, by conventional chemistry. Alternatively, such monomers may be obtained commercially. For example, PEGacrylate, diacrylate, methacrylate and dimethacrylate are commercially available from Aldrich (Gillingham, Dorset, UK.).

The unsaturated moiety may be attached to the polyalkylene glycol or polytetrahydrofuran by means of any suitable linkage groups, for example via a methyl ether linkage. Hence, it is possible to use poly (ethylene glycol) methyl ether methacrylate (available from Aldrich Chemicals). One advantage of using the living radical polymerisation technique is that commercially available compounds such as this, which have free-radical inhibitors, such as hydroquinones, may be used without further purification. With conventional free-radical-based systems the presence of a free-radical inhibitor will inhibit the addition polymerisation reaction. This is not the case with living radical polymerisation.

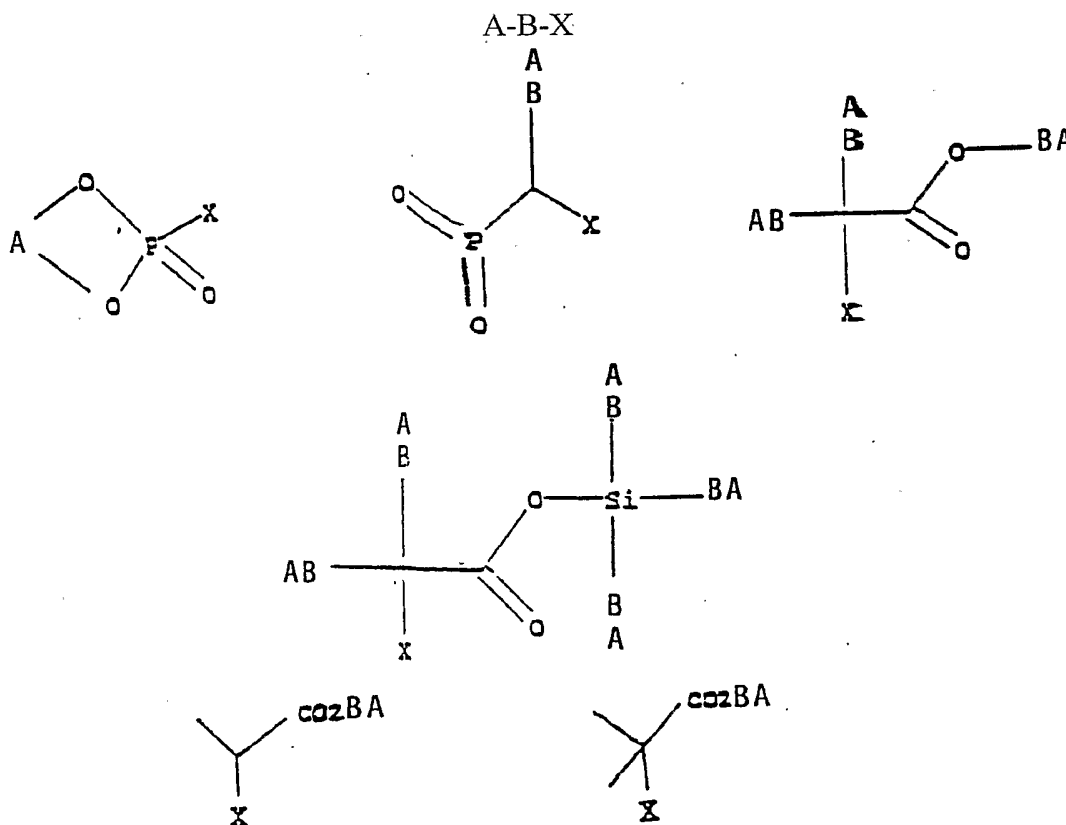
The initiator compound may comprise a homolytically cleavable bond with a halogen atom. This may contain a bond that breaks without integral charge formation on either atom by homolytic fission. As described in WO 97/01589, WO 99/28352 and WO 01/94424, it is believed that true free-radicals do not appear to be formed using some catalysts. It is believed that this occurs in a concerted fashion whereby the monomer is inserted into the bond without formation of a discrete free-radical species in the system. That is, during propagation this results in the formation of a new carbon-carbon bond and a new carbon-halogen bond without free-radical formation. A free-radical which is an atom or group of atoms having an unpaired valance electron and which is a separate entity without interactions, is not produced by the interaction of the initiator compound with the monomer with which it interacts.

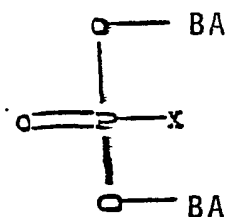
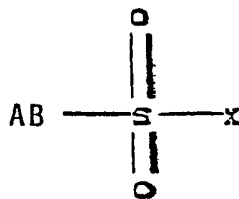
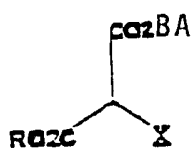
Suitable initiator compounds are described in, for example, WO 97/47661. However, it is preferable that the initiator compound also comprises a moiety which, when attached to the comb polymer, is capable of binding to a protein or polypeptide. These moieties are known in the art, as indeed described in Roberts, *et al.* (Supra), Chapman (Supra) and, for example, in the catalogues of Enzon and Shearwater.

The initiator may be a thioester or xanthate. These are used in so-called RAFT (Reversible Addition Fragmentation chain transfer and nitric oxide mediated polymerisation) and MADIX catalysation. The initiators and their reactions are described in WO 99/31144, WO 98/01478 and US 6,153,705.

Preferably, the initiator compound (ii) is selected from:

A-S-C(O)-R, A-S-C(S)-O-R, R-S-C(O)-A, R-S-C(S)-O-A, where R is C₁ to C₂₀ substituted or non-substituted, straight chain, branched chain, cyclic, heterocyclic or aromatic alkyl;





where: X = a halide, especially Cl or Br,

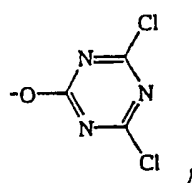
A = a moiety which, when attached to the comb polymer, is capable of binding to a protein or polypeptide,

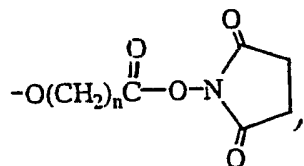
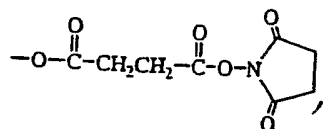
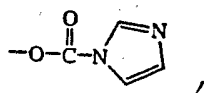
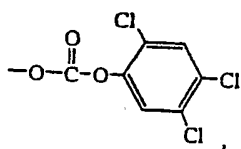
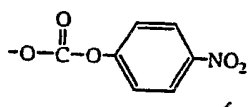
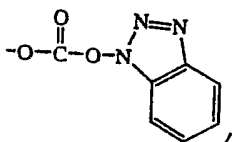
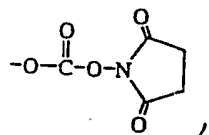
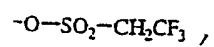
B is a linker and may or may not be present.

A is preferably selected from succinimidyl succinate, N-hydroxy succinimide, succinimidyl propionate, succinimidyl butanoate, propionaldehyde, acetaldehyde, tresylate, triazine, vinylsulfone, benzotriazole carbonate, maleimide, pyridyl sulfide, iodoacetamide and succinimidyl carbonate.

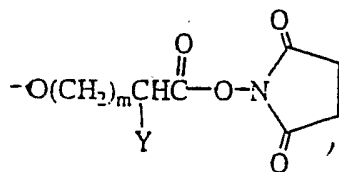
The linker is preferably selected from a C_1 to C_{20} substituted or non-substituted, straight chain, branched chain cyclic, heterocyclic or aromatic alkyl group; $-(CH_2Z)_aCH_2-$, $-CH_2ZCH_2-$, $-(CH_2CH_2Z)_n-R$, $-(CH_2CH(CH_3)Z)_n-R$, $-(CH_2)_b-C(O)-NH-(CH_2)_c-$, $-(CH_2)_a-NH-C(O)-(CH_2)_y-$, $-N(R)_2-$, $-S-$, $-N-R$; or $-O-R$; where R = C_1 to C_{20} substituted or non-substituted, straight chain, branched chain cyclic, heterocyclic or aromatic alkyl, Z is O or S, and n, a, b and c are independently selectable integers between 1 and 10. Preferably, the linker contains 1, 2, 3, 4, 5, 6, 7, 8, 9 or 10 carbon atoms. Most preferably, the linker is methyl, ethyl, propyl, butyl or pentyl.

Preferably, the moiety which is capable of reacting with the protein or polypeptide has the formula:

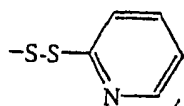
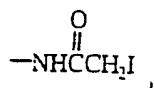


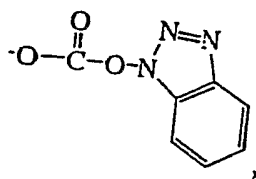
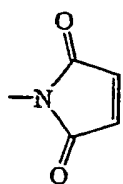


where $n = \text{integer of } 0 \text{ to } 10$

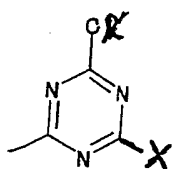


where $m = \text{integer of } 0 \text{ to } 10$, Y is an aliphatic or aromatic moiety



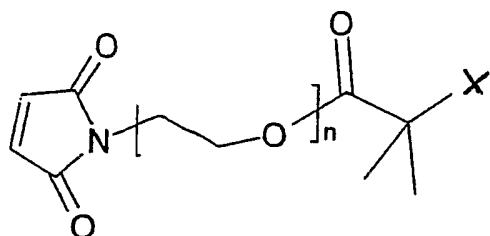
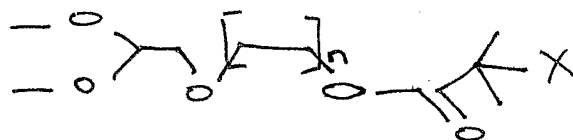
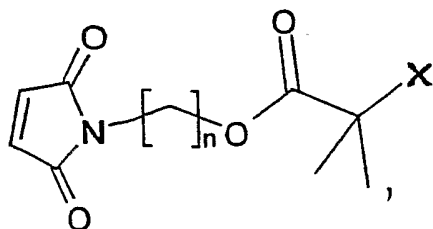


and



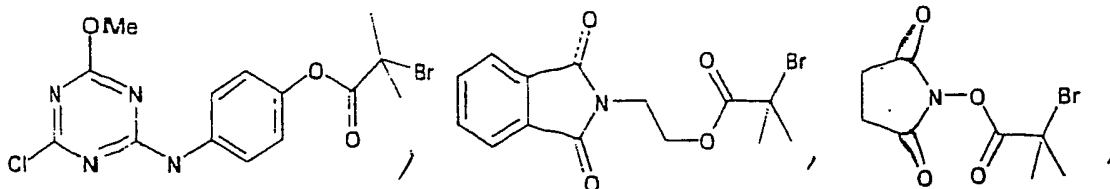
where R' is H, methyl, ethyl, propyl or butyl, X is a halide, especially Cl or Br.

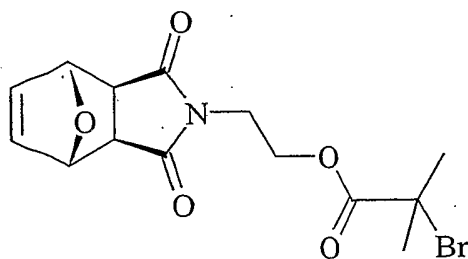
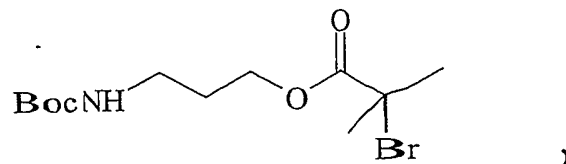
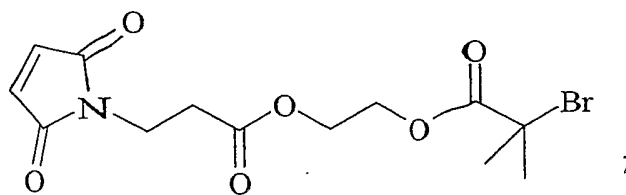
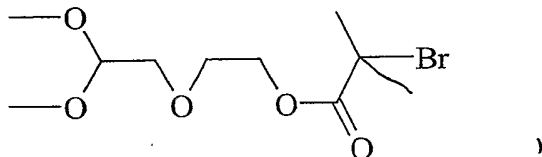
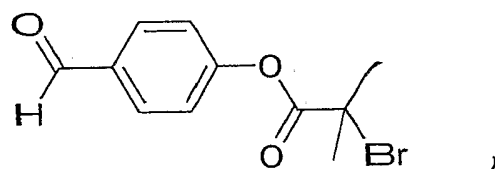
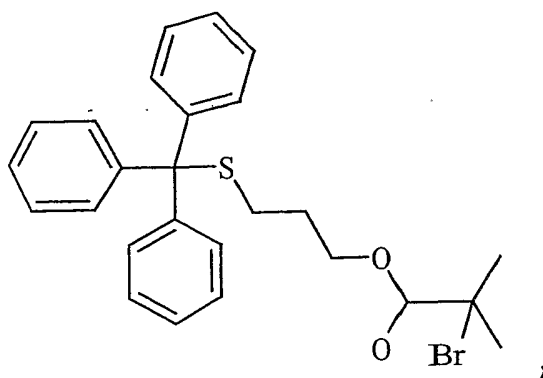
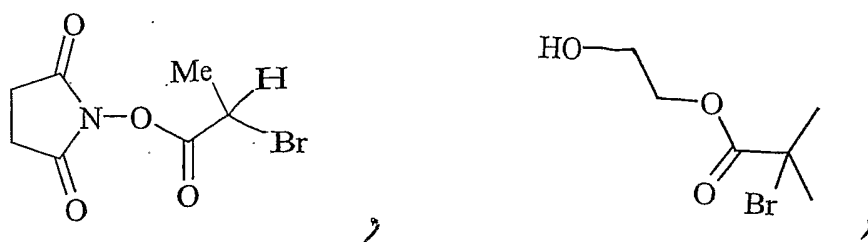
Most preferably, the initiator (ii) has a formula:



where n is an integer of 0 to 10, and X is a halide, especially Cl or Br.

The initiator has a compound selected from:





The catalyst may be capable of catalysing the polymerisation reaction by living radical polymerisation (see e.g. WO 97/47661) or living free radical polymerisation (see e.g. WO 96/30421, WO 97/18247 and Kamagaito M., *et al.*, Chem. Rev. (2001), Vol. 101 (12), pages 3689-3745).

Preferably the catalyst comprises a ligand which is any N-, O-, P- or S- containing compound which can coordinate in a δ -bond to a transition metal or any carbon-containing compound which can coordinate in a π -bond to the transition metal, such that direct bonds between the transition metal and growing polymer radicals are not formed.

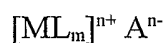
The catalyst may comprise a first compound



where: M is a transition metal having an oxidation state which is capable of being oxidised by one formal oxidation state,

Y is a mono, divalent or polyvalent counterion.

The catalyst may also be defined by the formula:



where: M = a transition metal having an oxidation state which is capable of being oxidised by one formal oxidation state,

L = an organodiimine where at least one of the nitrogens of the diimine is not part of an aromatic ring,

A = anion,

n = integer of 1 to 3,

m = an integer of 1 to 2.

The metal ion may be attached to a coordinating ligand, such as $(CH_3CN)_4$. Y may be chosen from Cl, Br, F, I, NO_3 , PF_6 , BF_4 , SO_4 , CN , SPh, SCN, SePh or triflate (CF_3SO_3). Copper (I) triflate may be used. This is available in the form of a commercially available benzene complex $(CF_3SO_3Cu)_2C_6H_6$.

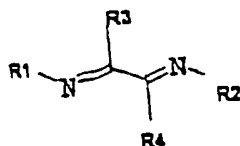
The especially preferred compound used is CuBr.

A may be F, Cl, Br, I, N, O_3 , SO_4 or CuX_2 (where X is a halogen).

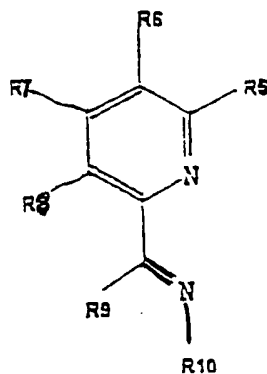
The transition metal may be selected from Cu^+ , Cu^{2+} , Fe^{2+} , Fe^{3+} , Ru^{2+} , Ru^{3+} , Cr^{2+} , Cr^{3+} , Mo^{2+} , Mo^{3+} , W^{2+} , W^{3+} , Mn^{3+} , Mn^{4+} , Rh^{3+} , Rh^{4+} , Re^{2+} , Re^{3+} , Co^+ , Co^{2+} , V^{2+} , V^{3+} , Zn^+ , Zn^{2+} , Au^+ , Au^{2+} , Ag^+ and Ag^{2+} .

Preferably the organodiimine has a formula selected from:

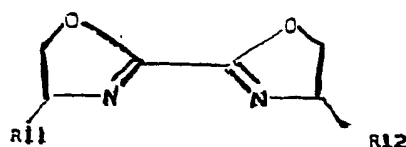
a 1,4-diaza-1,3-butadiene



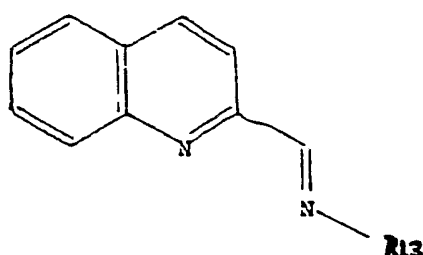
a 2-pyridine carbaldehyde imine



an oxazolidone.

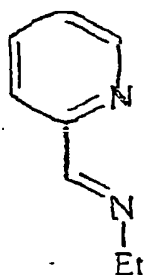


or a quinoline carbaldehyde

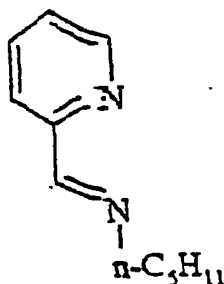


where R_1 , R_2 , R_{10} , R_{11} , R_{12} and R_{13} may be varied independently and R_1 , R_2 , R_{10} , R_{11} , R_{12} and R_{13} may be H, straight chain, branched chain or cyclic saturated alkyl, hydroxyalkyl, carboxyalkyl, aryl (such as phenyl or phenyl substituted where substitution is as described for R_4 to R_9) CH_2Ar (where Ar = aryl or substituted aryl) or a halogen. Preferably R_1 , R_2 , R_{10} , R_{11} , R_{12} and R_{13} may be a C_1 to C_{20} alkyl, hydroxyalkyl or carboxyalkyl, in particular C_1 to C_4 alkyl, especially methyl or ethyl, n-propylisopropyl, n-butyl, sec-butyl, tert butyl, cyclohexyl, 2-ethylhexyl, octyl decyl or lauryl.

Preferred ligands include:



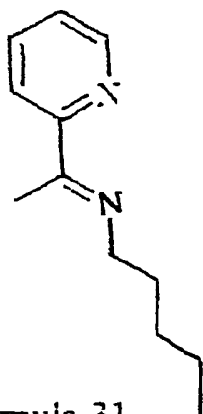
Formula 28



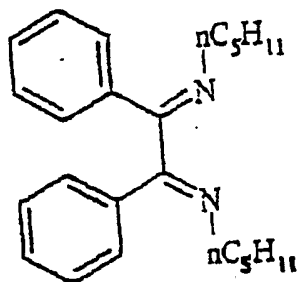
Formula 29



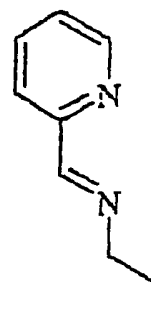
Formula 30



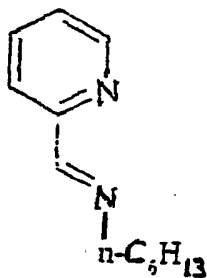
Formula 31



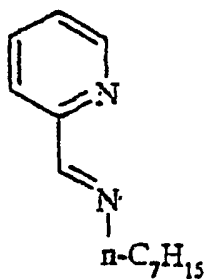
Formula 32



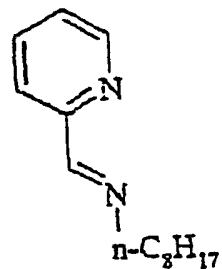
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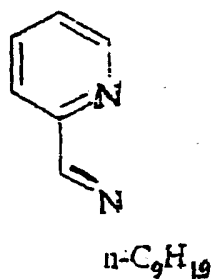
Formula 34



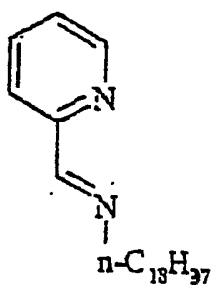
Formula 35



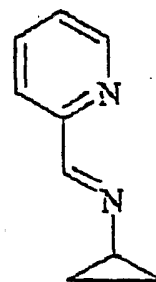
Formula 36



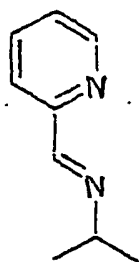
Formula 37



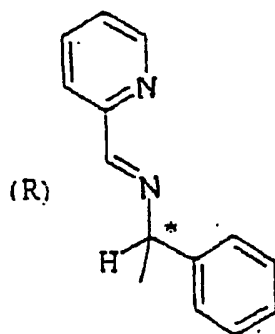
Formula 38



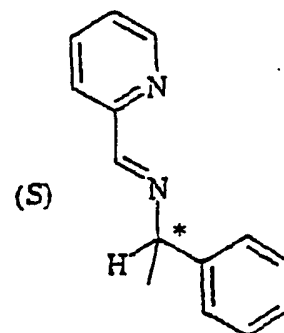
Formula 39



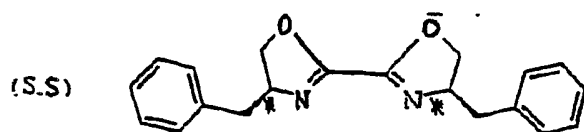
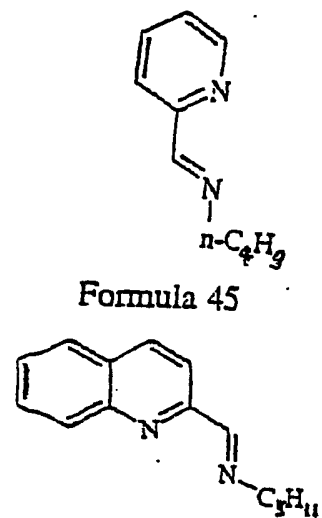
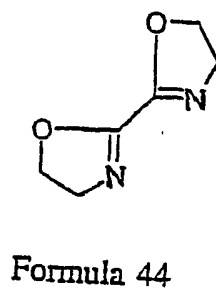
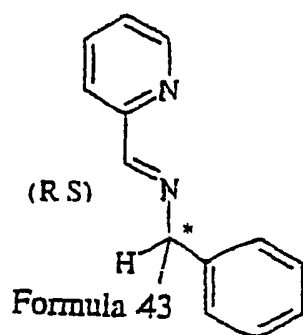
Formula 40



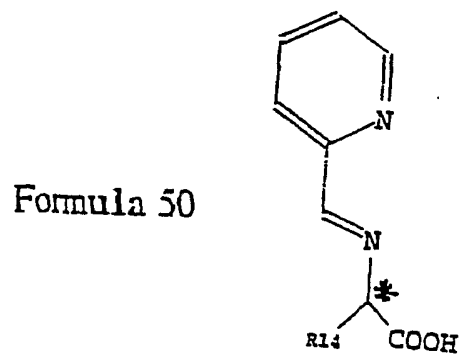
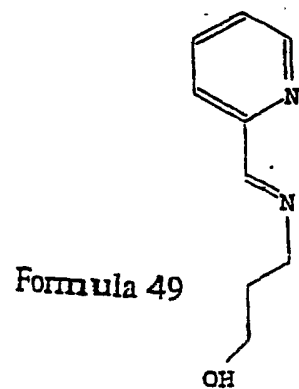
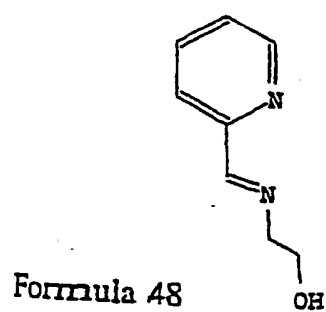
Formula 41



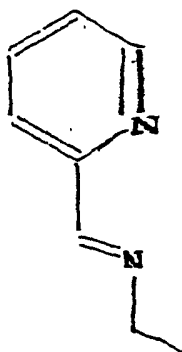
Formula 42



Formula 47



and



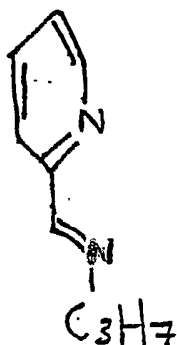
Formula 51

where: * indicates a chiral centre

COOH

R14 = Hydrogen, C₁ to C₁₀ branched chain alkyl, carboxy- orhydroxy- C₁ to C₁₀ alkyl.hydroxy- C₁ to C₁₀ alkyl.

Preferably the catalyst is

with Cu₂Br₂

Preferably the organodiimine is N-(n-propyl)-2-pyridylmethanimine (NMPI), N-ethyl-2-pyridyl methanimine or N-(n-ethyl)-2-pyridylmethanimine.

Other catalysts are described in WO 96/30421 and WO 97/18247.

Preferably the catalyst comprises a bipyridine group, such as 4,4'-di(5-nonyl)-2,2'-bipyridyl (dNbpy).

A plurality of different monomers as defined in part (i) of the invention may be used. This allows the production of statistical co-polymers.

Alternatively, or additionally, a block co-polymer may be produced by additionally polymerising one or more different olefinically unsaturated monomers. For example, the olefinically unsaturated monomers may be selected from methyl methacrylate, ethyl methacrylate, propyl methacrylate (all isomers), butyl methacrylate (all isomers), and other alkyl methacrylates; corresponding acrylates; also functionalised methacrylates and acrylates including glycidyl methacrylate, trimethoxysilyl propyl methacrylate, allyl methacrylate, hydroxyethyl methacrylate, hydroxypropyl methacrylate, dialkylaminoalkyl methacrylates; fluoroalkyl (meth)acrylates; methacrylic acid, acrylic acid; fumaric acid (and esters), itaconic acid (and esters), maleic anhydride; styrene, α -methyl styrene; vinyl halides such as vinyl chloride and vinyl fluoride; acrylonitrile, methacrylonitrile; vinylidene halides of formula $\text{CH}_2 = \text{C}(\text{Hal})_2$ where each halogen is independently Cl or F; optionally substituted butadienes of the formula $\text{CH}_2 = \text{C}(\text{R}^{15}) \text{C}(\text{R}^{15}) = \text{CH}_2$ where R^{15} is independently H, C_1 to C_{10} alkyl, Cl, or F; sulphonic acids or derivatives thereof of formula $\text{CH}_2 = \text{CHSO}_2\text{OM}$ wherein M is Na, K, Li, $\text{N}(\text{R}^{16})_4$ where each R^{16} is independently H or C_1 to C_{10} alkyl, COZ , ON , $\text{N}(\text{R}^{16})_2$ or SO_2OZ and Z is H, Li, Na, K or $\text{N}(\text{R}^{16})_4$; acrylamide or derivatives thereof of formula $\text{CH}_2 = \text{CHCON}(\text{R}^{16})_2$ and methacrylamide or derivative thereof of formula $\text{CH}_2 = \text{C}(\text{CH}_3)\text{CON}(\text{R}^{16})_2$.

The monomers may be polymerised prior to or after the polymerisation of the monomers as defined in part (i) of the invention.

The polymerisation reaction may be reactive in a number of different solvents, such as hydrophobic or hydrophilic solvents. These include water, propionitrile, hexane, heptane, dimethoxyethane, diethoxyethane, tetrahydrofuran, ethylacetate, diethylether,

N,N-dimethylformamide, anisole, acetonitrile, diphenylether, methylisobutyrate, butan-2-one, toluene and xylene.

The reaction temperature may be carried out from -20 to greater than 200°C, especially +5 to 130°C. WO 97/47661, for example, shows examples of living radical polymerisation and the typical conditions that may be used.

Preferably, the ratio of organodiimine : transition metal is 0.01 to 1000, preferably 0.1 to 10, and transition metal ion (as MY) : initiator is 0.0001 to 1000, preferably 0.1 to 10, where the degree of polymerisation is controlled by the ratio of monomer to initiator. All ratios are given as weight : weight. Preferably the components are the catalyst of formula: $[ML_m]^{n+}A^{n-}$ (defined above) are at a ratio of catalyst : initiator of 3 : 1 to 1 : 100.

Preferably, the amount of diimine : metal used in the system is between 100 : 1 and 1 : 1, preferably 5 : 1 to 1 : 1, more preferably 3 : 1 to 1 : 1, by weight.

Preferably the concentration of monomer in a solvent used is 100% - 1%, preferably 100% - 5%, vol. : vol.

Preferred ratios of initiator to catalyst or 1 : 100 - 100 : 1, typically 1 : 1.

Preferred ratios of monomer : initiator are 1 : 1 to 10,000 : 1, especially 5 : 1 to 100 : 1.

The reaction may be undertaken under an inert atmosphere such as nitrogen or argon, and may be carried out in suspension, emulsion, mini-emulsion or in a dispersion.

Preferably, the catalyst is a supported catalyst, that is, at least a part of the catalyst is attached to a support. Such supported catalysts are shown in, for example, WO 99/28352.

The support may be inorganic, such as silica, especially silica gel. Alternatively, the support may be organic, especially an organic polymer, such as a cross-linked organic polymer, including poly(styrene-w-divinylbenzene). The support may be in the form of

beads. The advantage of using a supported catalyst is that it allows the catalyst to be removed from the system and recycled/reused.

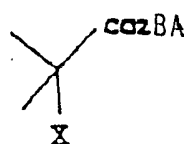
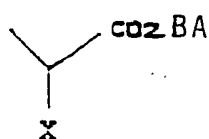
The comb polymer may incorporate a fluorescently-labelled monomer. For example, the method may additionally comprise a step of copolymerising or block polymerising with at least one fluorescently-labelled monomer capable of undergoing addition polymerisation. This can be carried out simply by using a monomer which has a fluorescent moiety, such as fluorescein, or coumarin, attached to an olefinically unsaturated moiety. The olefinically unsaturated moiety may be selected from those unsaturated moieties defined above.

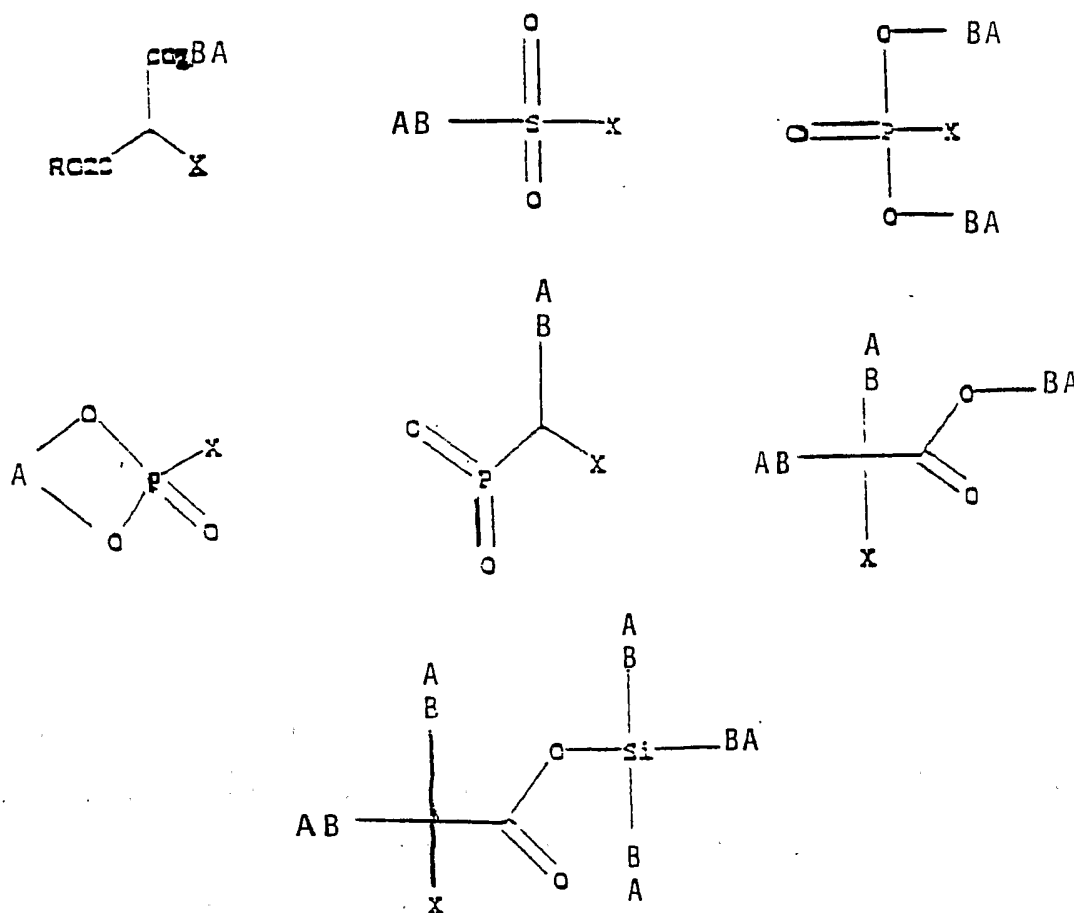
Preferably, the fluorescent label is coumarin, especially coumarin 343. Coumarin is particularly advantageous because it allows the comb polymer to be used to attach to proteins and the attachment of the proteins to be visualised using a confocal microscope. This allows, for example, the detection of individual proteins or indeed the visualisation of whole bacterial or other cells. Indeed, initial results have indicated that bacterial cells can be readily visualised, using a comb polymer according to the invention, to attach to *E.coli* and *Streptomyces* cells.

A further aspect of the invention provides initiator compounds capable of being used in a living radical polymerisation reaction comprising a moiety which, when attached to a polymer, is capable of binding to a protein or polypeptide. Initiators for use in a living radical polymerisation reaction having the following formulae are also provided:

A-S-C(O)-R, A-S-C(S)-O-R, R-S-C(O)-A, R-S-C(S)-O-A, where R is C₁ to C₂₀ substituted or non-substituted, straight chain, branched chain, cyclic, heterocyclic or aromatic alkyl;

A-B-X





where: X = a halide, especially Cl or Br,

A = a moiety which, when attached to the comb polymer, is capable of binding to a protein or polypeptide,

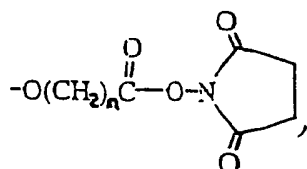
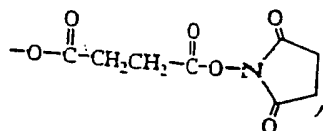
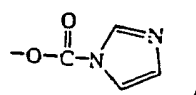
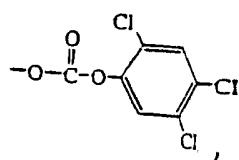
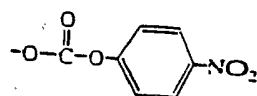
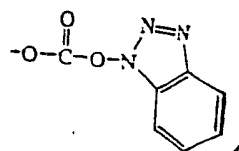
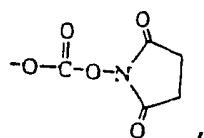
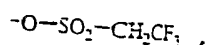
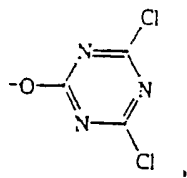
B is a linker and may or may not be present.

Preferably, A is selected from succinimidyl succinate, N-hydroxy succinimide, succinimidyl propionate, succinimidyl butanoate, propionaldehyde, acetaldehyde, tresylate, triazine, vinyl sulfone, benzotriazole carbonate, maleimide, pyridyl sulfide, iodoacetamide and succinimidyl carbonate.

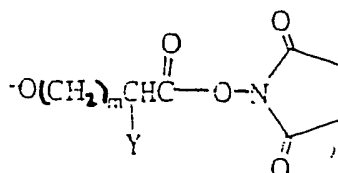
Preferably, the linker is selected from a C_1 to C_{20} substituted or non-substituted, straight chain, branched chain cyclic, heterocyclic or aromatic alkyl group; $-(CH_2Z)_aCH_2-$, $-CH_2ZCH_2-$, $-(CH_2CH_2Z)_n-R$, $-(CH_2CH(CH_3)Z)_n-R$, $-(CH_2)_b-C(O)-NH-(CH_2)_c-$, $-(CH_2)_a-NH-C(O)-(CH_2)_y-$, $-N(R)_2-$, $-S-$, $-N-R$; or $-O-R$; where $R = C_1$ to C_{20} substituted

or non-substituted, straight chain, branched chain cyclic, heterocyclic or aromatic alkyl, Z is O or S, and n, a, b and c are independently selectable integers between 1 and 10.

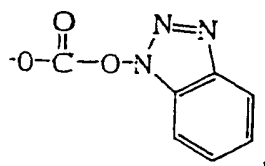
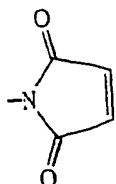
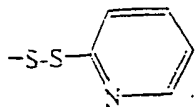
Preferably the moiety capable of reacting with a protein or polypeptide has a formula:



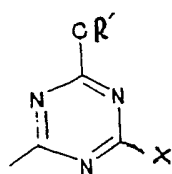
where $n =$ integer of 0 to 10



where m = integer of 0 to 10, Y is an aliphatic or aromatic moiety

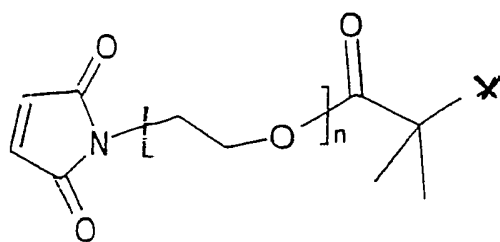
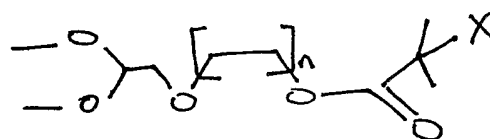
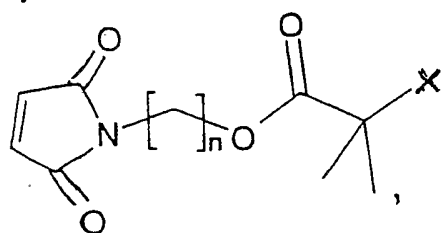


and



where R' is H, methyl, ethyl, propyl or butyl, X is a halide, especially Cl or Br.

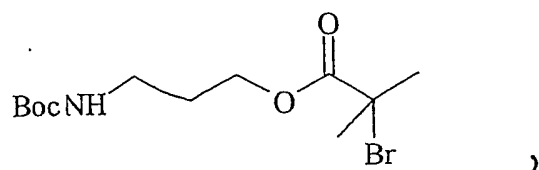
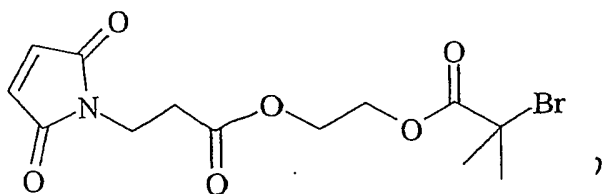
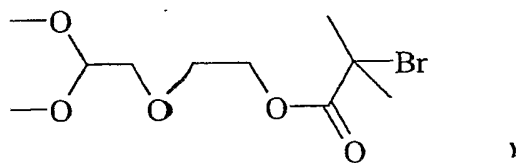
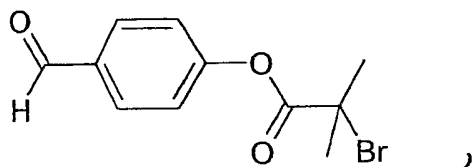
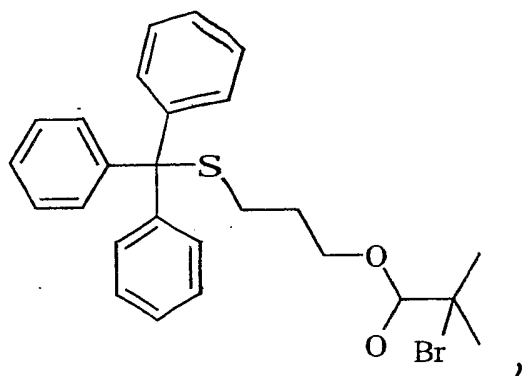
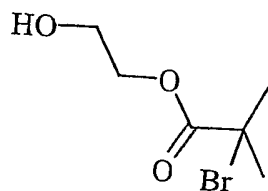
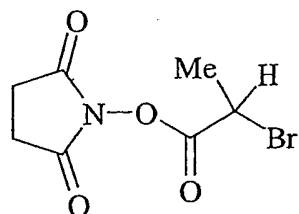
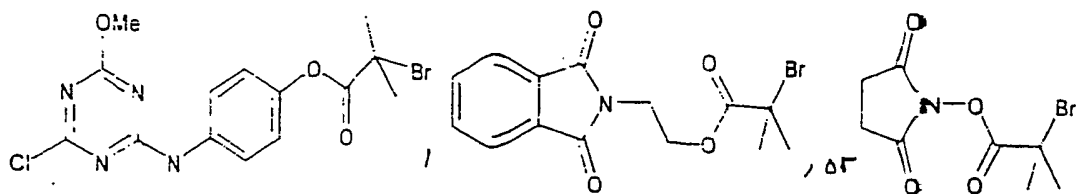
Preferably the initiator has a formula of:



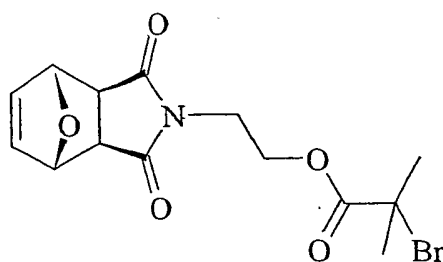
where n is an integer of 0 to 10, and X is a halide, especially Cl or Br.

The initiator especially has the formula:

25



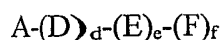
26



Under normal conditions, the aldehyde-based initiators will tend to react non-selectively with proteins, i.e. they will react substantially equally with both terminal nitrogen atoms and, for example, a lysine NH₂ group, if the reaction conditions are not controlled. However, under the right reaction pKa for the particular aldehyde chosen, the aldehyde can be controlled to specifically target the terminal nitrogen.

A further aspect of the invention provides comb polymers capable of binding a protein or polypeptide obtainable by a method of the invention.

A further aspect provides a comb polymer having a general formula:



where: A may or may not be present, and where present is a moiety capable of binding to a protein or a polypeptide,

D, where present, is obtainable by additional polymerisation of one or more olefinically unsaturated monomers which are not as defined in E.

E is obtainable by additional polymerisation of a plurality of monomers which are linear, branched, or star-shaped, substituted or non-substituted, and have an olefinically unsaturated moiety.

F, where present, is obtainable by additional polymerisation of one or more olefinically unsaturated monomers which are not as defined in E.

d and f are an integer between 0 and 500, especially 0 to 300 or 0 to 100.

e is an integer of 0 to 1000, especially 0 to 10, 50, 100, 200, 300, 400, 500, 600, 700, 800 or 900

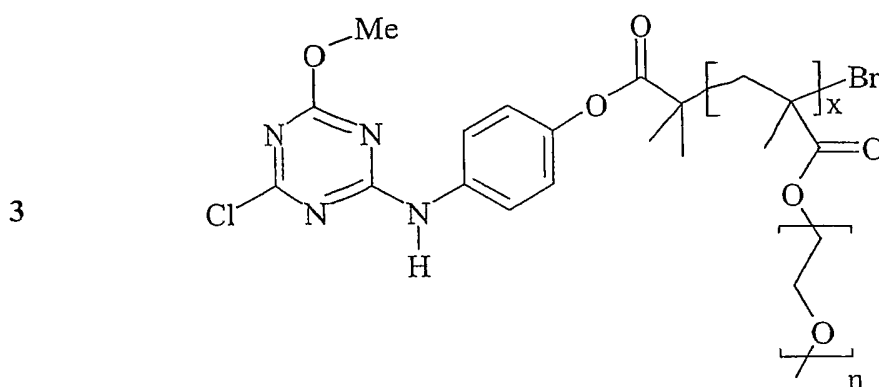
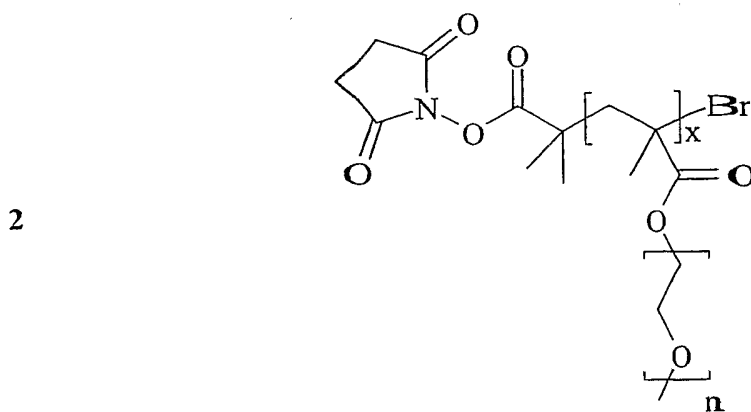
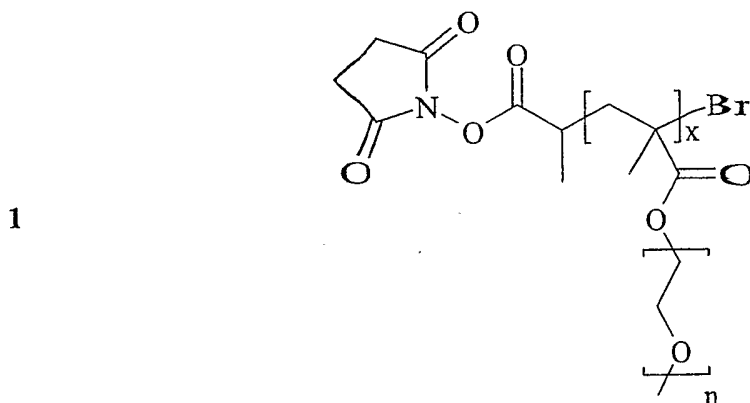
and wherein when A is present, at least one of D, E and F is present.

Preferred monomers used to obtain E are poly (alkylene glycol) or polytetrahydrofuran.

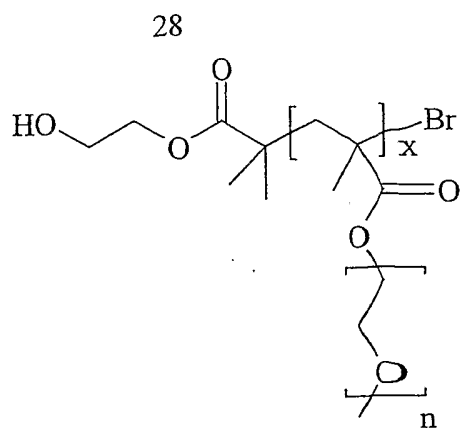
This includes both functionalised comb polymer and non-functionalised comb polymer, where the moiety capable of attaching to a protein or polypeptide may be attached later by other chemistry.

Preferably the comb polymer has an average total molecular weight of 2,000-80,000, especially 20,000-40,000.

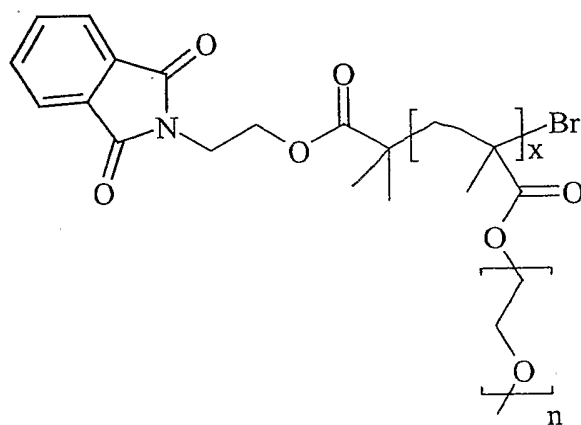
Examples of preferred comb polymers, obtainable according to the process of the invention, are:



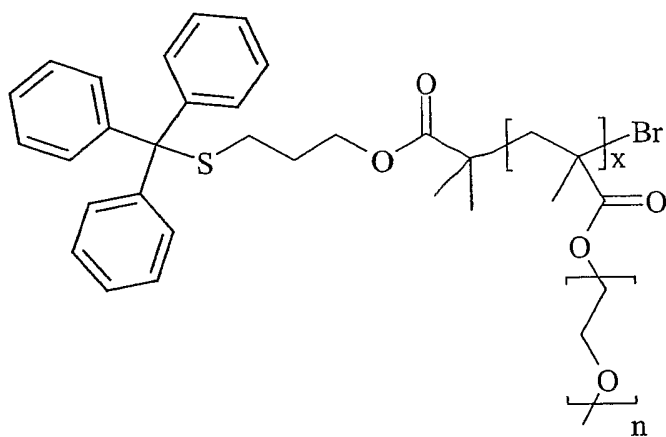
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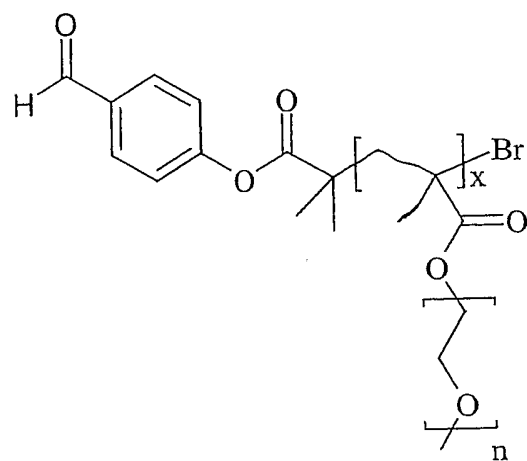
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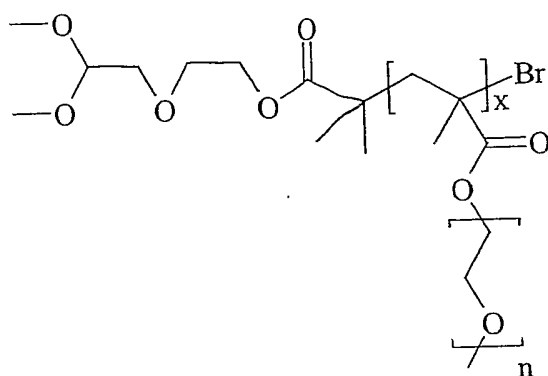


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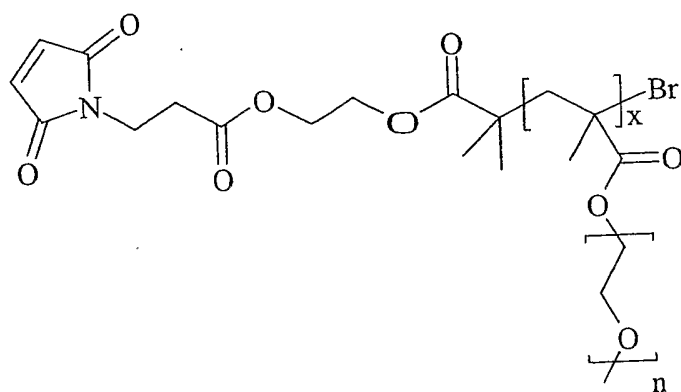


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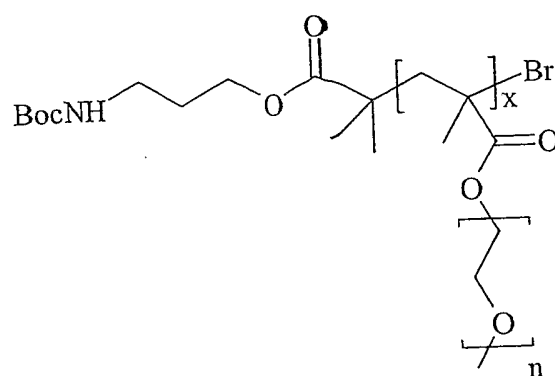
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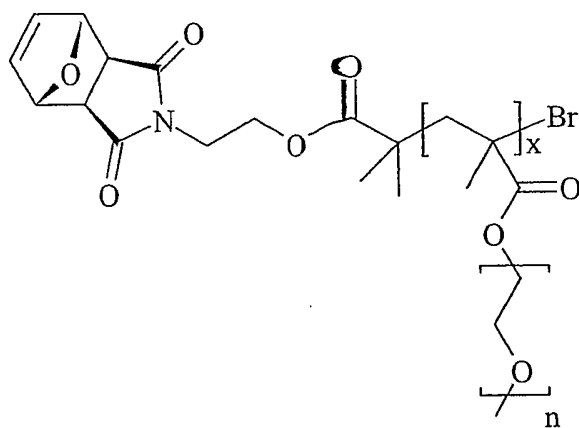
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11



These polymers can be used either directly to react with useful biomolecules or converted simply into new macromolecules that will react with useful biomolecules.

The comb polymer may be fluorescently labelled, especially with a coumarin. A still further aspect of the invention provides a method of attaching a polymer to a compound comprising reacting a comb polymer according to the invention with said compound. The compound may be a protein or polypeptide or may indeed be any compound having a suitable free thiol or free amine group, depending on the initiator used. Such compounds include amines, such as benzylamines and ethylenediamine, amino acids and carbohydrates such as sugars.

Preferably such compounds are biologically-active compounds, such as drugs. The combination of such compounds in combination with a pharmaceutically acceptable carrier are also provided. The compounds may include cancer chemotherapeutic agents, antibiotics, anti-fungal and/or immunosuppressants.

For example, Figures 23 and 24 show HPLC traces and SDS-PAGE for the reaction of lysozyme with a polymer prepared according to the invention. These figures clearly illustrate the progress of the reaction as the polymer selectively conjugates to only one of lysozyme's seven amino groups.

A still further aspect of the invention provides a method of fluorescently labelling a compound, virus, microorganism or cell comprising the step of reacting the compound, virus, microorganism or cell with a fluorescently labelled comb polymer according to the invention. The use of a comb polymer as a fluorescent label is also provided.

The fluorescently labelled comb polymer may be used to attach antibodies which in turn may be used to selectively bind to pre-defined antigens. This allows the selective labelling of the compounds to take place.

Methods of producing such antibodies are well-known in the art and indeed monoclonal antibodies may be produced by the well-known Kohler-Milstein method.

Previously, when polymers have been used to bind to proteins, they have had to be of a low molecular weight, as a polymer with a molecular weight of e.g. 20,000 could not be excreted from the body by the liver. To combat this problem, four polymers of approximately 5,000 molecular weight each were bound to the protein, and eventually excreted without problem. An advantage that is provided by the comb polymers of the invention is that they can possess molecular weights of 20,000 and still be bound to the proteins without the problems of excretion found with conventional polymers. This is due to an ester linkage which is found in each "finger" of the comb polymer. Preliminary results show that this ester linkage is readily hydrolysed by enzymes, causing the fingers to gradually break off the main polymer backbone. This enables a 20,000 molecular weight polymer to become smaller over time until it reaches a molecular weight which enables it to be excreted by the liver. Conventional chain polymers cannot offer this advantage but remain in the bloodstream without being excreted.

Initial results indicate that the comb polymers of the invention are stable over weeks in rat serum, but slowly break down in the manner detailed above.

The invention will now be described by way of example only with reference to the following examples:

Figure 1 shows the evolution of molecular weight distribution and polydispersity for the LRP (living radical polymerisation) of methyl methacrylate initiated by a N-hydroxysuccinimide (NHS) initiator.

Figure 2 shows SEC curves for NHS functionalised poly (MMA), solid curve, and the produce (N-benzylamide functionalised poly (MMA), dashed curve).

Figure 3. First order kinetic plot for the LRP of PEGMA initiated by NHS-Br, $[\text{PEGMA}]_0/[\text{CuBr}]_0/[\text{NHSBr}]_0/[\text{L}]_0 = 10/1/1/2.1$ in toluene (33% v/v) at 30°C.

Figure 4. Evolution of the molecular weight distribution and polydispersity for the LRP of PEGMA initiated by NHS-Br, $[\text{PEGMA}]_0/[\text{CuBr}]_0/[\text{NHSBr}]_0/[\text{L}]_0 = 10/1/1/2.1$ in toluene (33% v/v) at 30°C.

Figure 5. Evolution of the molecular weight distribution and polydispersity for the LRP of MPEG(395)MA initiated using initiator 1, $[\text{MPEG(395)MA}]_0/[\text{CuBr}]_0/[\text{NHSBr}]_0 = 10/1/1/2$ in toluene (50% v/v) at 30°C.

Figure 6. Selected region (2.7-4.3 ppm) of the ^1H NMR spectrum of a NHS ester functionalised poly(MPEG(395)MA) prepared from initiator 1 ($M_n = 6400 \text{ g.mol}^{-1}$, $M_w/M_n = 1.09$).

Figure 7. First order kinetic plot for the LRP of MPEG(395)MA using initiator 2, $[\text{MPEG(395)MA}]_0/[\text{CuBr}]_0/[\text{NHSBr}]_0/[\text{Propyl Ligand}]_0 = 10/1/1/2$ in toluene (50% v/v) at 30°C.

Figure 8. Evolution of the molecular weight distribution and polydispersity for the LRP of MPEG(395)MA using initiator 2, $[\text{MPEG(395)MA}]_0/[\text{CuBr}]_0/[\text{NHSBr}]_0/[\text{Propyl Ligand}]_0 = 10/1/1/2$ in toluene at 30°C.

Figure 9. Rate plot for TMM-LRP of MPEG(1000)MA initiator 8, $[\text{monomer}]:[\text{initiator}]:[\text{CuCl}]:[\text{L}] = 5:1:2:2$, $T = 70^\circ\text{C}$.

Figure 10. Dependence of M_n on conversion for MPEG(1000)MA initiator 8, $[\text{monomer}]:[\text{initiator}]:[\text{CuCl}]:[\text{L}] = 5:1:1:2$, $T = 70^\circ\text{C}$.

Figure 11. Rate plot for TMM-LRP of MPEG(1000)MA initiator 8, $[\text{monomer}]:[\text{initiator}]:[\text{CuBr}]:[\text{L}] = 20:1:1:2$, $T = 50^\circ\text{C}$.

Figure 12. Dependence of M_n on conversion for TMM-LRP of MPEG(1000)MA initiator 8, $[\text{monomer}]:[\text{initiator}]:[\text{CuBr}]:[\text{L}] = 20:1:1:2$, $T = 50^\circ\text{C}$.

Figure 13. Rate plot for TMM-LRP of MPEG(395)MA using initiator **10**, [monomer]:[initiator]:[CuBr]:[L] = 6:1:1:2.

Figure 14. Dependence of M_n on conversion for TMM-LRP of MPEG(395)MA using initiator **10**, [monomer]:[initiator]:[CuBr]:[L] = 6:1:1:2.

Figure 15. Rate plot for TMM-LRP of MPEG(395)MA using initiator **10**, [monomer]:[initiator]:[CuBr]:[L] = 28:1:1:2. T = 40°C.

Figure 16. Dependence of M_n on conversion for TMM-LRP of MPEG(395)MA using initiator **10**, [monomer]:[initiator]:[CuBr]:[L] = 6:1:1:2. T = 40°C.

Figure 17. Rate plot for TMM-LRP of MPEG(395)MA using initiator **10**, [monomer]:[initiator]:[CuBr]:[L] = 28:1:1:2. T = 60°C.

Figure 18. Dependence of M_n on conversion for TMM-LRP of MPEG(395)MA using initiator **10**, [monomer]:[initiator]:[CuBr]:[L] = 6:1:1:2. T = 60°C.

Figure 19. Online ^1H NMR experiment: Rate plot for TMM-LRP of MPEG(395)MA using initiator **10**, [monomer]:[initiator]:[CuBr]:[L] = 10:1:1:2. T = 40°C.

Figure 20. Rate plot for TMM-LRP of MPEG(395)MA using initiator **11**, [monomer]:[initiator]:[CuBr]:[L] = 8:1:1:2. T = 30°C.

Figure 21. Dependence of M_n on conversion for TMM-LRP of MPEG(395)MA using initiator **11**, [monomer]:[initiator]:[CuBr]:[L] = 8:1:1:2. T = 30°C.

Figure 22. Kinetic plot for the hydrolysis of N-succinimidyl terminated poly(MPEG(395)MA initiated by **1** in different buffers.

Figure 23. HPLC traces for the reaction of succinimide terminated poly(MPEG(395)MA) prepared from initiator **1** ($M_n = 6400 \text{ g.mol}^{-1}$, $M_w/M_n = 1.11$) with Lysozyme ([polymer] / [lysozyme] 20:1).

Figure 24. SDS-PAGE for the conjugation of lysozyme with succinimide terminated poly(MPEG(395)MA) prepared from initiator **1** ($M_n = 6400 \text{ g.mol}^{-1}$, $M_w/M_n = 1.11$) (20 equivalents).

Figure 25. HPLC traces for the reaction of succinimide terminated poly(MPEG(395)MA) prepared from initiator **1** ($M_n = 6400 \text{ g.mol}^{-1}$, $M_w/M_n = 1.11$) with Lysozyme ([polymer] / [lysozyme] 5:1).

Figure 26. HPLC traces for the reaction of succinimide terminated poly(MPEG(395)MA) prepared from initiator **1** ($M_n = 6400 \text{ g.mol}^{-1}$, $M_w/M_n = 1.11$) with Lysozyme ([polymer] / [lysozyme] 2:1).

Figure 27. Comparison of the HPLC traces of various conjugates of lysozyme obtained with different ratios of polymer/lysozyme using succinimide terminated poly(MPEG(395)MA) prepared from initiator **1**.

Figure 28. Kinetic plot for the hydrolysis of the succinimide end group of poly(MPEG(395)MA) polymer initiated by **2** in different buffers.

Figure 29. ^1H NMR spectrum of a NHS ester functionalised (initiator **2**) poly(MPEG(395)MA) ($M_n = 2700 \text{ g.mol}^{-1}$, $M_w/M_n = 1.12$).

Figure 30. ^1H NMR spectrum of a N-benzylamide functionalised poly(MPEG(395)MA) ($M_n = 2800 \text{ g.mol}^{-1}$, $M_w/M_n = 1.15$).

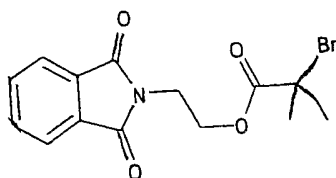
Figure 31. HPLC traces for the reaction of poly(MPEG(395)MA) prepared from initiator **2** ($M_n = 2700 \text{ g.mol}^{-1}$, $M_w/M_n = 1.12$) with lysozyme ([polymer] / [lysozyme] 30:1).

Figure 32. SDS-PAGE for the conjugation of poly(MPEG(395)MA) prepared from initiator 2 with lysozyme at different reaction time and different ratio polymer / protein (a) 5/1, (b) 10/1 and (c) 30/1.

Figure 33. SEC-HPLC chromatography of the conjugation reaction of Lysozyme with the aldehyde-terminated polymer ($M_n \sim 22,000$, PDI 1.09).

Figure 34. Retro-Diels-Alder reaction: ($\blacksquare$ = "initiator" and $\blacktriangle$ = maleimido signals) a) $t = 0$; b) $t = 3.5$ h; c) $t = 7$ h.

Synthesis of *N*-[2-(2'-bromo-2'-methylpropionyloxy)-ethyl]phthalimide, 6.

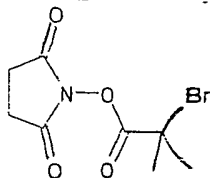


N-(2-hydroxyethyl)phthalimide (Aldrich, 99%) (19.12 g, 0.1 mol) was dissolved in anhydrous THF (250 mL) with triethylamine (28.1 mL, 0.2 mol) under nitrogen in a 500 mL round-bottomed flask equipped with a magnetic stirrer. The flask was cooled to 0°C with an ice bath before the dropwise addition of 2-bromoisobutyryl bromide (13.9 mL, 0.11 mol). The mixture was stirred for 45 minutes and allowed to reach room temperature. Subsequently the reaction mixture was poured into an excess of cold water and extracted with diethyl ether (3 $\times$ 50 mL). The organic layer was washed with a saturated aqueous solution of Na_2CO_3 (3 $\times$ 50 mL), acidified water (pH = 4.5, 3 $\times$ 50 mL), and again the saturated aqueous solution of Na_2CO_3 (3 $\times$ 50 mL). The organic layer was dried over anhydrous MgSO_4 and filtered. Finally the solvent was removed under reduced pressure by using the rotary evaporator in order to isolate the title compound (30.6 g, yield 90 %) as a yellowish solid.

m.p. 63-65°C, IR (solid, ATR cell) ν (cm^{-1}) 1774 ($\text{C}_{\text{cycl}}=\text{O}$), 1705 ($\text{C}=\text{O}$); ^1H NMR (CDCl_3 , 298 K, 300 MHz) δ 1.81 (s, 6H, $\text{C}(\text{CH}_3)_2\text{Br}$), 3.95 (t, 2H, $J = 5.3$ Hz, CH_2N), 4.35 (t, 2H, $J = 5.4$ Hz, CH_2O), 7.67 (m, 2H, CH Ar), 7.78 (m, 2H, CH Ar). ^{13}C NMR (CDCl_3 , 298 K, 75 MHz) δ 31.00 (2C, $\text{C}(\text{CH}_3)_2\text{Br}$), 37.12 (1C, CH_2N), 55.92 (1C, $\text{C}(\text{CH}_3)_2\text{Br}$), 63.42 (1C,

CH₂O), 123.78 (2C, CH Ar), 132.35 (1C, C Ar), 133.54 (2C, CH Ar), 168.40 (2C, C_{cycl}=O), 171.87 (1C, C=O).

Synthesis of *N*-(2-bromo-2-methylpropionyloxy) succinimide, 7.



This was prepared from *N*-hydroxysuccinimide (NHS) using a similar procedure to that given above for the synthesis of compound 6. The solvent used in this case was anhydrous dichloromethane as NHS is insoluble in THF. The title compound was obtained in 85 % yield as a white solid.

m.p. 72–74°C; IR (solid, ATR cell) ν (cm⁻¹) 1772 (C_{cycl}=O), 1728 (C=O); ¹H NMR (CDCl₃, 298 K, 300 MHz) δ 2.08 (s, 6H, C(CH₃)₂Br), 2.87 (s, 4H, CH₂). ¹³C NMR (CDCl₃, 298 K, 75 MHz) δ 26.03 (2C, CH₂), 31.09 (2C, C(CH₃)₂Br), 51.60 (1C, C(CH₃)₂Br), 167.89 (1C, C=O), 169.02 (2C, C_{cycl}=O); MS (+EI), (m/z) 266, 265, 156, 151, 149, 123, 121, 116, 115, 91, 87, 70, 69. Anal. Calcd for C₈H₁₀NO₄Br: C = 36.39; H = 3.82; N = 5.30, Br = 30.26. Found: C = 36.35; H = 3.82; N = 5.03; Br = 30.17.

4-[(4-chloro-6-methoxy-1,3,5-triazin-2-yl)amino]phenol, 4.

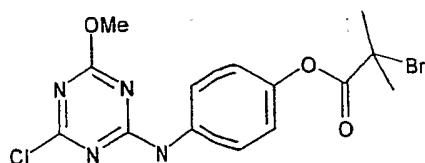
A solution of 2,4-dichloro-6-methoxy-1,3,5-triazine²⁹ (9.00 g, 50.0 mmol) in 100 mL of acetone was cooled to 0 °C and, under stirring, solid 4-aminophenol (5.46 g, 50.0 mmol) was added in small portions over ca. 2 min. The white suspension was then left to warm to ambient temperature and stirred for further 1 h, whilst being neutralized with a 2 M aqueous solution of Na₂CO₃. The mixture was then poured into 500 mL of ice/water and the resulting white precipitate was filtered and dried, to give 9.60 g (38.0 mmol, yield 76%) of 4-[(4-chloro-6-methoxy-1,3,5-triazin-2-yl)amino]phenol that can be used for the next step without further purifications. An analytical sample was obtained by flash chromatography (CC, SiO₂, petroleum ether/ Et₂O 1:1, R_f = 0.14). The NMR analysis (d₆-DMSO) revealed the presence, in solution, of 2 rotational isomers (molar ratio 7:3).

m.p. 172 °C dec.; IR $\nu_{\text{(NH)}}$ 3476 cm^{-1} . $\nu_{\text{(OH)}}$ 3269 cm^{-1} .

Major isomer ^1H NMR (d_6 -DMSO, 298K, 300 MHz) δ 3.94 (s, 3H, OCH_3); 6.79 (d, $J = 8.8$ Hz, 2H, CH Ar), 7.48 (d, $J = 8.8$ Hz, 2H, CH Ar), 9.40 (s, 1H, OH), 10.46 (s, 1H, NH); $^{13}\text{C}\{^1\text{H}\}$ NMR (d_6 -DMSO, 298K, 75 MHz) δ 55.52 (1C, OCH_3); 115.46 (2C, CH Ar), 123.91 (2C, CH Ar), 129.49 (1C, C Ar), 154.44 (1C, C Ar), 164.81 (1C, C Ar), 169.57 (1C, C Ar), 171.23 (1C, C Ar).

Minor isomer ^1H NMR (d_6 -DMSO, 298K, 300 MHz) δ 3.96 (s, 3H, OCH_3); 6.79 (d, $J = 8.9$ Hz, 2H, CH Ar), 7.39 (d, $J = 8.9$ Hz, 2H, CH Ar), 9.42 (bs, 1H, OH), 10.10 (s, 1H, NH); $^{13}\text{C}\{^1\text{H}\}$ NMR (d_6 -DMSO, 298 K, 75 MHz) δ 55.10 (1C, OCH_3); 115.46 (2C, CH Ar), 123.03 (2C, CH Ar), 129.26 (1C, C Ar), 154.76 (1C, C Ar), 165.20 (1C, C Ar), 170.48 (1C, C Ar), 170.64 (1C, C Ar); Anal. Calcd for $\text{C}_{10}\text{H}_9\text{ClN}_4\text{O}_2$: C = 47.54, H = 3.59, N = 22.18, Cl = 14.03, Found: C = 47.57, H = 3.55, N = 22.10, Cl = 14.8.

4-[(4-chloro-6-methoxy-1,3,5-triazin-2-yl)amino]phenyl 2-bromo-2-methylpropionate, 5



A solution of 2-bromoisobutyryl bromide (1.0 mL, 7.90 mmol) in 20 mL of THF was added dropwise to a solution of 4-[(4-chloro-6-methoxy-1,3,5-triazin-2-yl)amino]phenol (1.9 g, 7.52 mmol) and triethylamine in 100 mL of THF, at -10 °C. During the addition (ca. 15 min) precipitation of triethylammonium bromide was observed. The reaction was monitored by TLC (SiO_2 , petroleum ether/ Et_2O 1:1, 4-[(4-chloro-6-methoxy-1,3,5-triazin-2-yl)amino]phenol (starting material) $R_f = 0.14$;

4-[(4-chloro-6-methoxy-1,3,5-triazin-2-yl)amino]phenyl 2-bromo-2-methylpropionate (final product) $R_f = 0.26$). After 1.5 h the white suspension was poured into a conical flask containing 150 mL of Et_2O and the ammonium salt removed by filtration on a sintered glass frit. The solvent was then evaporated at reduced pressure to give a white crude residue that was suspended in 10 mL of pentane and filtered. We obtained 2.56 g (6.37 mmol, yield 85%) of 4-[(4-chloro-6-methoxy-1,3,5-triazin-2-yl)amino]phenyl 2-bromo-2-methylpropionate as a white solid. The ^1H NMR analysis (d_6 -DMSO) revealed the presence, in solution, of 2 rotational isomers (molar ratio 7:3).

m.p. 107-108 °C; IR $\nu_{\text{(NH)}}$ 3365 cm^{-1} . $\nu_{\text{(C=O)}}$ 1747 cm^{-1} .

Major isomer: ^1H NMR (d_6 -DMSO, 298 K, 400 MHz) δ 2.05 (s, 6H, $\text{C}(\text{CH}_3)_2\text{Br}$), 3.96 (s, 3H, OCH_3), 7.17 (d, $J = 8.9$ Hz, 2H, CH Ar), 7.77 (d, $J = 8.9$ Hz, 2H, CH Ar), 10.78 (s, 1H, NH); $^{13}\text{C}\{^1\text{H}\}$ NMR (d_6 -DMSO, 298 K, 100.6 MHz) δ 30.42 (2C, CH_3), 55.75 (bs, 1C, OCH_3), 57.29 (1C, $\text{C}(\text{CH}_3)_2\text{Br}$), 121.96 (2C, CH Ar), 122.12 (2C, CH Ar), 136.29 (1C, C Ar), 146.61 (bs, 1C, C Ar), 165.10 (bs, 1C, C Ar), 169.89 (bs, 1C, C Ar), , 170.16 (1C, C=O), 171.33 (bs, 1C, C Ar).

Minor isomer: ^1H NMR (d_6 -DMSO, 298 K, 400 MHz) δ 2.05 (s, 6H, $\text{C}(\text{CH}_3)_2\text{Br}$), 3.96 (s, 3H, OCH_3), 7.17 (d, $J = 8.9$ Hz, 2H, CH Ar), 7.69 (d, $J = 8.9$ Hz, 2H, CH Ar), 10.66 (s, 1H, NH); $^{13}\text{C}\{^1\text{H}\}$ NMR (d_6 -DMSO, 298 K, 100.6 MHz) δ 30.42 (2C, CH_3), 55.75 (bs, 1C, OCH_3), 57.29 (1C, $\text{C}(\text{CH}_3)_2\text{Br}$), 121.96 (2C, CH Ar), 122.73 (2C, CH Ar), 136.29 (1C, C Ar), 146.61 (bs, 1C, C Ar), 165.10 (bs, 1C, C Ar), 169.89 (bs, 1C, C Ar), , 170.16 (1C, C=O), 171.33 (bs, 1C, C Ar).

Typical Polymerisation of MMA.

CuBr (0.134 g, 0.934 mmol) was placed in an oven-dried Schlenk tube. The tube was fitted with a rubber septum, evacuated and flushed with dry N_2 three times. Methyl methacrylate (10 mL, 93.4 mmol) and xylene (20 mL) were transferred to the tube via degassed syringe. The mixture was stirred rapidly under nitrogen and *N*-(*n*-propyl)-2-pyridylmethanimine (NMPI) (0.408 g, 1.86 mmol) was added which imparted a deep red/brown colour to the solution. Appropriate initiator (0.934 mmol) was added and the resulting solution was degassed by three freeze-pump-thaw cycles. The resulting mixture was placed in a thermostatically controlled oil bath at 90 °C. Samples were taken periodically for conversion and molecular weight analysis. Conversion was measured by gravimetry by drying to constant weight in a vacuum oven at 70 °C. The catalyst was removed from the samples by passing through a column of activated basic alumina prior to SEC. (see Figure 1).

Table 1 Polymerisation of MMA in Xylene Solution (33% v/v) at 90 °C

Initiator	[MMA]/[Cu(I)Br]/[Cu(II)Br ₂]/[NMPi]/[Initiator]	Time Min	M _n g mol ⁻¹	PDI	Conv. %	k _p [Pol*] * 10 ⁴ s ⁻¹
5	100/1/0/2/1 ^c	480	8200	1.14	66	
6	100/1/0/1/2.1	600	8900 (9000 ^b)	1.20	75	0.047
7	37/1/0/1/2.1	138	5800 (5800 ^b)	1.05	89	0.32
7	60/0.95/0.05/1/2.1	2880	3200 (3100 ^b)	1.04	37	0.22
EiBr	100/1/0/2/1 ^d	2880	2500 (2400 ^b)	1.16	71	

^a k_p[Pol*] = rate constant of propagation × [active propagating polymer chains] from first order kinetic plot.

^b determined by the ¹H NMR peak intensity ratio on a Bruker DPX 300 MHz

^c *N*-(*n*-octyl)-2-pyridylmethanimine used as the ligand

^d 10 mole % HEMA/90 mole % MMA

Typical Polymerisation of Styrene.

CuBr (0.055 g, 0.38 mmol) was placed in an oven dried Schlenk tube. The tube was fitted with a rubber septum, evacuated and flushed three times with dry N₂. Styrene (10 mL, 96 mmol) was transferred to the tube via degassed syringe. The mixture was stirred rapidly under nitrogen and 4,4'-di(5-nonyl)-2,2'-bipyridyl (dNbpy) (0.314 g, 0.768 mmol) was added, imparting a deep red/brown colour to the solution. Initiator 1 (0.035 g, 0.048 mmol, 0.192 mmol of initiating sites) was added and the resulting solution was degassed by three freeze-pump-thaw cycles. The resulting mixture was placed in a thermostatically controlled oil bath at 110 °C for 4.5 hours. The catalyst was removed from the samples by passing through a column of activated basic alumina prior to SEC.

Kinetic studies for initiators 6 and 7.

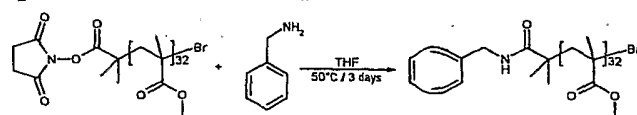
Samples were removed periodically using degassed syringes and quenched in liquid nitrogen for conversion and molecular weight analysis. Conversion was determined by NMR on a Bruker DPX 300. For Living Radical Polymerisation initiated by 6, samples were passed over a basic alumina column and then filtered in a syringe equipped with a 0.22 µm hydrophobic filter prior to molecular weight studies. In the case of LRP initiated

by 7, molecular weight was determined by diluting the sample with THF and letting it settle overnight to precipitate the catalyst residues. The upper liquid was then filtered with a 0.22 μm hydrophobic filter. This method was chosen for N-hydroxysuccinimide-functionalised polymers as these polymers could not be passed over basic alumina.

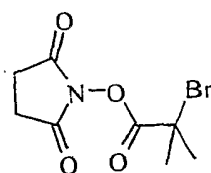
Synthesis of a N-benzylamide functionalised poly(MMA).

Benzylamine was added to a solution of N-hydroxysuccinimide terminated poly(methyl methacrylate) in anhydrous THF. N-hydroxysuccinimide-terminated poly(methyl methacrylate) ($M_n = 3200 \text{ g mol}^{-1}$, PDI = 1.06) (1.00 g, 0.313 mmol) and three equivalents of benzylamine (0.100 mL, 0.938 mmol) were dissolved in 10 mL of dry THF in a dry Schlenk and stirred at 50 °C for 3 days under nitrogen. After reaction, the polymer was precipitated in cold petroleum ether (see Figure 2).

This shows that N-benzylamide functional groups may be added and can be used to reach with free amide groups of the sort found in proteins.



Scheme Coupling of a N-hydroxysuccinimide terminated poly(MMA) with benzylamine.



(1)

N-hydroxysuccinimide initiator **(1)** (NHS-Br)

Reagents.

Poly(ethylene glycol) methyl ether methacrylate ($M_n = ca\ 475$, Aldrich, 99%) and anhydrous toluene was degassed by bubbling with dry nitrogen for 30 minutes before use. The ligand N-(*n*-propyl)-2-pyridylmethanimine was prepared as described previously¹.

Copper(I) bromide (Avocado, 98%) was purified as necessary by a method based on that of Keller and Wycoff². Other reagents were all commercial products and used without further purification.

Typical procedure.

Polymerizations were carried out at 30°C mediated by copper(I) bromide / N-(*n*-propyl)-2-pyridylmethanimine. A typical polymerization recipe is based on 33% v/v monomer in toluene. The ratio of initiator/Cu(I)Br/ligand is 1/1/2.1 on a molar basis. A dry Schlenk tube was charged with Cu(I)Br (0.3099 g, 2.16×10^{-3} mol), NHS-Br (1) (0.5704 g, 2.16×10^{-3} mol) and a magnetic bar prior to being deoxygenated by cycling between nitrogen and vacuum three times. To the flask was then added PEGMA (10 ml, 2.27×10^{-2} mol) and toluene (20 ml). The mixture was immediately subjected to three freeze-pump-thaw degassing cycles. Finally N-(*n*-propyl)-2-pyridylmethanimine (0.707 ml, 4.54×10^{-3} mol) was added and the flask was placed in an oil bath thermostatted at 30°C.

Kinetic studies.

Samples were removed periodically using degassed syringes and quenched in liquid nitrogen for conversion and molecular weight analysis. Conversion was determined by NMR on a Bruker DPX 300 MHz. Molecular weight was determined by diluting the sample with toluene and allowing it to settle down overnight to remove the copper complexes. The upper liquid was then filtered with a 0.22µm hydrophobic filter. This method was chosen because of the difficulty encountered to pass the polymer over a basic alumina column. Number average molecular weights (M_n) were determined by Size Exclusion Chromatography (SEC) in a system fitted with a 5 mm guard column, two Polymer Labs mixed E columns, a differential refractive index detector, and an auto sampler. The system was eluted with THF at a rate of 1 mL/min. Toluene was used as the flow marker.

Purification.

N-hydroxysuccinimide functionalised poly(PEGMA) were purified by two consecutive purifications from a Toluene solution in diethyl ether.

Table 1. Kinetic data for the polymerisation of PEGMA initiated by NHS-Br in toluene solution (33% v/v) at 30°C ([PEGMA]₀/[CuBr]₀/[NHSBr]₀/[L]₀ = 10/1/1/2.1).

Time (h)	Conversion (%)	M _{n, exp} (g.mol ⁻¹)	M _w /M _n ^a	M _{n, theo} ^b (g.mol ⁻¹)
1	8.9	2350	1.10	450
2	18.4	2860	1.26	920
3	27.1	3100	1.20	1360
4	34.7	3600	1.13	1730
17	80.8	5670	1.06	4040

^a determined by SEC analysis calibrated with Poly(MMA) standards – THF. ^b M_{n, theo} = ([M]₀ / [I]₀ × M.W._{MMA} × Conv.) / 100.

Table 2. Characterisation of Poly(PEGMA) prepared by LRP

	K _p [Pol*] ^a (h ⁻¹)	M _{n, exp} ^b (g.mol ⁻¹)	M _w /M _n	M _{n, theo} ^b (g.mol ⁻¹)
NHS-Poly(PEGMA)	0.096	6200	1.05	4040

^a K_p[Pol*] = rate constant of propagation. ^b determined by SEC calibrated with Poly(MMA) standards – THF (stabilised with topanol). ^c M_{n, theo} = ([M]₀ / [I]₀ × M.W._{MMA} × Conv.) / 100.

References

- (a) D. M. Haddleton, M. C. Crossman, B. H. Dana, D. J. Duncalf, A. M. Henning, D. Kukulj and A. J. Shooter, *Macromolecules*, **1999**, 32, 2110.
 (b) R. N. Keller and W. D. Wycoff, *Inorg. Synth.*, **1947**, 2, 1.

Polymerisation of methoxypolyethylene glycol methacrylate (2080) using the initiator derived from N-hydroxy succinimide

[PEG]/[I]/[Cu]/[L] = 19.2/1/1/2 in 80% toluene solution (AJ U2-27a) @30°C

N-hydroxy succinimide initiator, (0.05 g, 0.189 mmol), Cu(I)Br (0.027 g, 0.189 mmol, 1 eq) and methoxypolyethyleneglycol methacrylate (PEG) (average molecular weight = 2080,

7.55 g, 3.63 mmol), and a magnetic follower were placed in an oven dried Schlenk tube. The Schlenk tube was evacuated and flushed with dry nitrogen three times. Deoxygenated toluene (28 mL) was added to the Schlenk tube. The resulting solution was deoxygenated via three freeze pump thaw cycles and then degassed *N*-ethyl-2-pyridylmethanimine (0.05 g, 0.38 mmol) was added. The reaction was placed in a thermostatically controlled oil bath at 30°C ($t=0$) and samples were removed periodically for conversion and molecular weight analysis. Conversion was followed by ^1H NMR spectrometry and molecular weight analysis by SEC.

The polymer was purified by the dropwise addition of the reaction solution to a vigorously stirred solution of diethyl ether (400 mL). The resulting white powder was filtered, dissolved in toluene (20mL) and precipitated in diethyl ether (400 mL). This procedure was repeated three times.

Table 1: Data for the polymerization of methoxypolyethyleneglycol methacrylate (2080) with an initiator derived from *N*-hydroxy succinimide at 30 °C in 80% toluene solution.

Sample Time / minutes	Conversion ^a / %	Mn ^b	PDI ^b
89	4	3380	1.04
291	9	9820	1.09
901	17	10030	1.07
1369	23	11080	1.07
2760	26	12610	1.07
3965	28	14830	1.04

^a Conversion was determined using ^1H NMR. ^b Molecular mass determined by SEC using PMMA standards.

Bisomer S20W (50% aqueous solution of methoxypolyethyleneglycol methacrylate) was freeze dried prior to use to remove all water.

[PEG]/[I]/[Cu]/[L] = 19.2/1/1/2 in 80% toluene solution (AJ U2-27b) @50°C

N-hydroxy succinimide initiator, (0.05 g, 0.189 mmol), Cu(I)Br (0.027 g, 0.189 mmol, 1 eq) and methoxypolyethyleneglycol methacrylate (PEG) (average molecular weight = 2080, 7.55 g, 3.63 mmol), and a magnetic follower were placed in an oven dried Schlenk tube. The Schlenk tube was evacuated and flushed with dry nitrogen three times. Deoxygenated toluene (28 mL) was added to the Schlenk tube. The resulting solution was deoxygenated via three freeze pump thaw cycles and then degassed *N*-ethyl-2-pyridylmethanimine (0.05 g, 0.38 mmol) was added. The reaction was placed in a thermostatically controlled oil bath at 50°C (t=0) and samples were removed periodically for conversion and molecular weight analysis. Conversion was followed by ¹H NMR spectrometry and molecular weight analysis by SEC.

The polymer was purified by the dropwise addition of the reaction solution to a vigorously stirred solution of diethyl ether (400 mL). The resulting white powder was filtered, dissolved in toluene (20 mL) and precipitated in diethyl ether (400 mL). This procedure was repeated three times.

Table 2: Data for the polymerization of methoxypolyethyleneglycol methacrylate (2080) with an initiator derived from N-hydroxy succinimide at 50 °C in 80% toluene solution.

Sample Time / minutes	Conversion ^a / %	Mn ^b	PDI ^b
86	7	8700	1.06
289	12	10920	1.07
899	24	14450	1.05
1367	33	15810	1.04
2758	45	20220	1.07
3962	53	23180	1.07

^a Conversion was determined using ¹H NMR. ^b Molecular mass determined by SEC using PMMA standards.

Bisomer S20W (50% aqueous solution of methoxypolyethyleneglycol methacrylate) was freeze dried prior to use to remove all water.

$[PEG]/[I]/[Cu]/[L] = 19.2/1/1/2$ in 80% toluene solution (AJ U2-27c) @90°C

N-hydroxy succinimide initiator, (0.05 g, 0.189 mmol), Cu(I)Br (0.027 g, 0.189 mmol, 1 eq) and methoxypolyethyleneglycol methacrylate (PEG) (average molecular weight = 2080, 7.55 g, 3.63 mmol), and a magnetic follower were placed in an oven dried Schlenk tube. The Schlenk tube was evacuated and flushed with dry nitrogen three times. Deoxygenated toluene (28 mL) was added to the Schlenk tube. The resulting solution was deoxygenated via three freeze pump thaw cycles and then degassed *N*-ethyl-2-pyridylmethanimine (0.05 g, 0.38 mmol) was added. The reaction was placed in a thermostatically controlled oil bath at 90°C ($t=0$) and samples were removed periodically for conversion and molecular weight analysis. Conversion was followed by 1H NMR spectrometry and molecular weight analysis by SEC.

The polymer was purified by the dropwise addition of the reaction solution to a vigorously stirred solution of diethyl ether (400 mL). The resulting white powder was filtered, dissolved in toluene (20mL) and precipitated in diethyl ether (400 mL). This procedure was repeated three times.

Table 3: Data for the polymerization of methoxypolyethyleneglycol methacrylate (2080) with an initiator derived from N-hydroxy succinimide at 90 °C in 80% toluene solution.

Sample Time / minutes	Conversion ^a / %	Mn ^b	PDI ^b
86	18	11100	1.08
289	26	14870	1.08
899	31	17900	1.08
1367	35	18110	1.09
2758	38	18110	1.09
3962	39	18240	1.08

^a Conversion was determined using ¹H NMR. ^b Molecular mass determined by SEC using PMMA standards.

Bisomer S20W (50% aqueous solution of methoxypolyethyleneglycol methacrylate) was freeze dried prior to use to remove all water.

$[PEG]/[I]/[Cu]/[L] = 23.9/1/1/2$ in 66% toluene solution (AJ U2-11) @90°C

N-hydroxy succinimide initiator, (2.5 g, 9.47 mmol), Cu(I)Br (1.35 g, 9.47 mmol, 1 eq) and methoxypolyethyleneglycol methacrylate (PEG) (average molecular weight = 628, 142.0 g, 0.226 mol), and a magnetic follower were placed in an oven dried Schlenk tube. The Schlenk tube was evacuated and flushed with dry nitrogen three times. Deoxygenated toluene (261 mL) was added to the Schlenk tube. The resulting solution was deoxygenated via three freeze pump thaw cycles and then degassed *N*-propyl-2-pyridylmethanimine (2.80 g, 0.019 mol) was added. The reaction was placed in a thermostatically controlled oil bath at 90°C (t=0) and samples were removed periodically for conversion and molecular weight analysis. Conversion was followed by ¹H NMR spectrometry and molecular weight analysis by SEC.

The polymer was purified by the dropwise addition of the reaction solution to a vigorously stirred solution of diethyl ether (1000 mL). The resulting oil was washed with diethyl ether (3 x 1000 mL) and then dried *in vacuo*.

Table 4: Data for the polymerization of methoxypolyethyleneglycol methacrylate (628) with an initiator derived from N-hydroxy succinimide at 90 °C in 66% toluene solution.

Sample Time / minutes	Conversion ^a / %	Mn ^b	PDI ^b
48	21	4449	1.11
132	40	7198	1.08
185	44	7779	1.07
245	46	8105	1.09
300	48	8331	1.09

^a Conversion was determined using ¹H NMR. ^b Molecular mass determined by SEC using PMMA standards.

Bisomer MPEG550MA was used as provided.

Polymerisation of methoxypolyethyleneglycol methacrylate (1080) using the N-hydroxy succinimide derived initiator

[PEG]/[I]/[Cu]/[L] = 13.9/1/1/2 in 66% toluene solution (AJ U2-13) @90°C

N-hydroxy succinimide initiator, (0.526 g, 1.99 mmol), Cu(I)Br (0.29 g, 2.02 mmol, 1 eq) and methoxypolyethyleneglycol methacrylate (PEG) (average molecular weight = 1080, 29.62 g, 0.027 mol), and a magnetic follower were placed in an oven dried Schlenk tube. The Schlenk tube was evacuated and flushed with dry nitrogen three times. Deoxygenated toluene (60 mL) was added to the Schlenk tube. The resulting solution was deoxygenated via three freeze pump thaw cycles and then degassed *N*-ethyl-2-pyridylmethanimine (0.51 g, 3.96 mol) was added. The reaction was placed in a thermostatically controlled oil bath at 90°C (*t*=0) and samples were removed periodically for conversion and molecular weight analysis. Conversion was followed by ¹H NMR spectrometry and molecular weight analysis by SEC.

The polymer was purified by the dropwise addition of the reaction solution to a vigorously stirred solution of diethyl ether (1000 mL). The resulting oil was washed with diethyl ether (3 x 1000 mL) and then dried *in vacuo*.

Table 5: Data for the polymerization of methoxypolyethyleneglycol methacrylate 1080) with an initiator derived from N-hydroxy succinimide at 90 °C in 66% toluene solution.

Sample Time / minutes	Conversion ^a / %	Mn ^b	PDi ^b
1250	47.3	12180	1.16
2460	50.4	12460	1.16
3890	52.8	12540	1.20

^a Conversion was determined using ¹H NMR. ^b Molecular mass determined by SEC using PMMA standards.

$[PEG]/[I]/[Cu]/[L] = 9.3/1/1/2$ in 66% toluene solution (AJ U2-15) @90°C

N-hydroxy succinimide initiator, (0.5 g, 1.89 mmol), Cu(I)Br (0.27 g, 1.89 mmol, 1 eq) and methoxypolyethyleneglycol methacrylate (PEG) (average molecular weight = 1080, 18.90 g, 0.018 mol), and a magnetic follower were placed in an oven dried Schlenk tube. The Schlenk tube was evacuated and flushed with dry nitrogen three times. Deoxygenated toluene (35 mL) was added to the Schlenk tube. The resulting solution was deoxygenated via three freeze pump thaw cycles and then degassed *N*-ethyl-2-pyridylmethanimine (0.51 g, 3.79 mmol) was added. The reaction was placed in a thermostatically controlled oil bath at 90°C (t=0) and samples were removed periodically for conversion and molecular weight analysis. Conversion was followed by ¹H NMR spectrometry and molecular weight analysis by SEC.

Table 6: Data for the polymerization of methoxypolyethyleneglycol methacrylate (1080) with an initiator derived from N-hydroxy succinimide at 90 °C in 66% toluene solution.

Sample Time /minutes	Conversion ^a / %	Mn ^b	PDI ^b
4160	88.7	9870	1.22

^a Conversion was determined using ¹H NMR. ^b Molecular mass determined by SEC using PMMA standards.

Bisomer S10W (50% aqueous solution of methoxypolyethyleneglycol methacrylate) was freeze dried prior to use to remove all water.

Polymerisation of methoxypolyethyleneglycol methacrylate (628) using the N-hydroxy succinimide derived initiator

$[PEG]/[I]/[Cu]/[L] = 6.4/1/1/2$ in 66% toluene solution (AJ U2-31a) @30°C

N-hydroxy succinimide initiator, (0.5 g, 1.89 mmol), Cu(I)Br (0.27 g, 1.89 mmol, 1 eq) and methoxypolyethyleneglycol methacrylate (PEG) (average molecular weight = 628, 7.57 g,

0.012 mol), and a magnetic follower were placed in an oven dried Schlenk tube. The Schlenk tube was evacuated and flushed with dry nitrogen three times. Deoxygenated toluene (14 mL) was added to the Schlenk tube. The resulting solution was deoxygenated via three freeze pump thaw cycles and then degassed *N*-ethyl-2-pyridylmethanimine (0.51 g, 3.79 mmol) was added. The reaction was placed in a thermostatically controlled oil bath at 30°C (t=0) and samples were removed periodically for conversion and molecular weight analysis. Conversion was followed by ¹H NMR spectrometry and molecular weight analysis by SEC.

Table 7: Data for the polymerization of methoxypolyethyleneglycol methacrylate (628) with an initiator derived from *N*-hydroxy succinimide at 30 °C in 66% toluene solution.

Sample Time / minutes	Conversion ^a / %	Mn ^b	PDI ^b
60	19	2850	1.04
131	32	3230	1.10
199	45	3560	1.12
250	53	3760	1.12
298	56	3980	1.12

^a Conversion was determined using ¹H NMR. ^b Molecular mass determined by SEC using PMMA standards.

Bisomer MPEG550MA was used as provided.

$[PEG]/[I]/[Cu]/[L] = 6.4/1/1/2$ in 66% toluene solution (AJ U2-31b) @50°C

N-hydroxy succinimide initiator, (0.5 g, 1.89 mmol), Cu(I)Br (0.27 g, 1.89 mmol, 1 eq) and methoxypolyethyleneglycol methacrylate (PEG) (average molecular weight = 628, 7.57 g, 0.012 mol), and a magnetic follower were placed in an oven dried Schlenk tube. The Schlenk tube was evacuated and flushed with dry nitrogen three times. Deoxygenated toluene (14 mL) was added to the Schlenk tube. The resulting solution was deoxygenated via three freeze pump thaw cycles and then degassed *N*-ethyl-2-pyridylmethanimine (0.51 g, 3.79 mmol) was added. The reaction was placed in a thermostatically controlled oil bath at 50°C (t=0) and samples were removed periodically for conversion and molecular weight

analysis. Conversion was followed by ^1H NMR spectrometry and molecular weight analysis by SEC.

Table 8: Data for the polymerization of methoxypolyethyleneglycol methacrylate (628) with an initiator derived from N-hydroxy succinimide at 50 °C in 66% toluene solution.

Sample Time / minutes	Conversion ^a / %	Mn ^b	PDI ^b
59	39	3212	1.09
126	56	3958	1.11
195	69	4375	1.13
246	75	4649	1.13
295	82	4874	1.13

^aConversion was determined using ^1H NMR. ^bMolecular mass determined by SEC using PMMA standards.

Bisomer MPEG550MA was used as provided.

Claims

1. A method of producing a comb polymer comprising the steps of:
 - (a) Providing:
 - (i) a plurality of monomers which are linear, branched or star-shaped, substituted or non-substituted, and have an olefinically unsaturated moiety, the olefinically unsaturated moiety being capable of undergoing addition polymerisation;
 - (ii) an initiator compound; the initiator compound comprising a homolytically cleavable bond.
 - (iii) a catalyst capable of catalysing the polymerisation of the monomer;and
 - (b) Causing the catalyst to catalyse, in combination with the initiator, the polymerisation of a plurality of the monomers to produce the comb polymer;wherein the initiator compound (ii) comprises a moiety which, when attached to the comb polymer, is capable of binding to a biological substance.
2. A method according to claim 1, wherein the monomers in (i) are alkoxy polyethers.
3. A method according to claim 2, wherein the alkoxy polyether is poly (alkylene glycol) or polytetrahydrofuran.
4. A method according to claims 1 to 3, wherein the biological substance is a protein or a polypeptide.
5. A method according to any one of claims 1 to 4, wherein the catalyst is capable of catalysing the polymerisation of the monomer by Living radical or living free radical polymerisation.

6. A method according to any preceding claim, wherein the catalyst comprises a ligand which is any N-, O-, P- or S-containing compound which can coordinate in a δ -bond to a transition metal or any carbon-containing compound which can coordinate in a π -bond to the transition metal, such that direct bonds between the transition metal and growing polymer radicals are not formed.

7. A method according to any one of claims 1 to 6, wherein the catalyst comprises:

a first compound MY, where M is a transition metal which is capable of being oxidised by one formal oxidation state, especially Cu^+ , Cu^{2+} , Fe^{2+} , Fe^{3+} , Ru^{2+} , Ru^{3+} , Cr^{2+} , Cr^{3+} , Mo^{2+} , Mo^{3+} , W^{2+} , W^{3+} , Mn^{3+} , Mn^{4+} , Rh^{3+} , Rh^{4+} , Re^{2+} , Re^{3+} , Co^+ , Co^{2+} , V^{2+} , V^{3+} , Zn^+ , Zn^{2+} , Au^+ , Au^{2+} , Ag^+ and Ag^{2+} , and Y is a monovalent or a divalent counterion; and

an organodiimine, wherein at least one of the nitrogens is not a part of an aromatic ring.

8. A method according to any one of claims 1 to 6 wherein the catalyst comprises a compound of formula:



where M = a transition metal capable of being oxidised by one formal oxidation state, especially Cu^+ , Cu^{2+} , Fe^{2+} , Fe^{3+} , Ru^{2+} , Ru^{3+} , Cr^{2+} , Cr^{3+} , Mo^{2+} , Mo^{3+} , W^{2+} , W^{3+} , Mn^{3+} , Mn^{4+} , Rh^{3+} , Rh^{4+} , Re^{2+} , Re^{3+} , Co^+ , Co^{2+} , V^{2+} , V^{3+} , Zn^+ , Zn^{2+} , Au^+ , Au^{2+} , Ag^+ and Ag^{2+} ,

A = an anion,

n = an integer of 1 to 3,

m = an integer of 1 to 2,

L = an organodiimine, where at least one of the nitrogens is not a part of an aromatic ring.

9. A method according to any preceding claim, wherein the olefinically unsaturated moiety is acrylate, methacrylate, methymethacrylate, styrene, methylacrylate, or a diene such as butadiene.

10. A method according to any preceding claim, wherein the poly (alkylene glycol) is poly (ethylene glycol) (PEG) or poly (propylene glycol).

11. A method according to claim 10, wherein the molecular weight of the PEG part of the monomer is between 450 and 20,000.

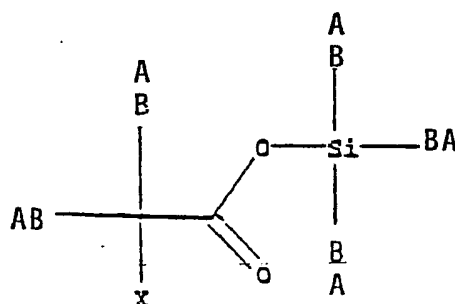
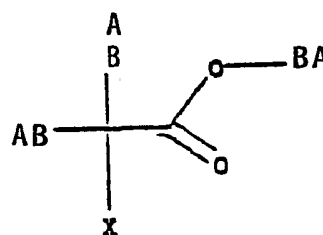
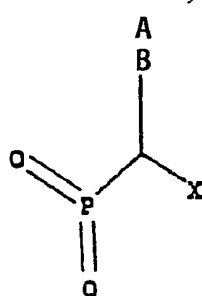
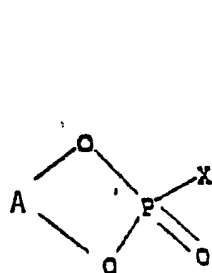
12. A method according to any preceding claim which uses an initiator which is a thioester containing compound or a xanthate.

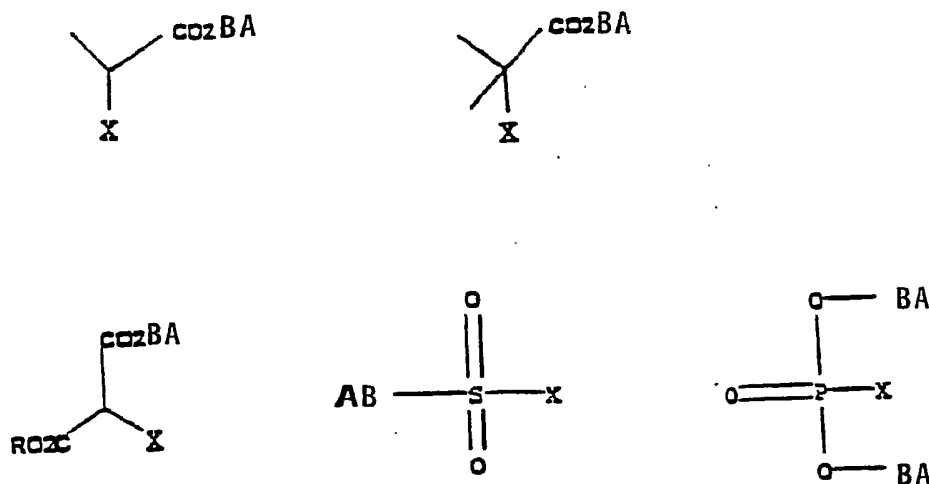
13. A method according to any one of claims 1 to 11, wherein the initiator comprises a homolytically cleavable bond with a halogen atom.

14. A method according to any one of claims 1 to 11, wherein the initiator compound (II) is selected from:

A-S-C(O)-R, A-S-C(S)-O-R, R-S-C(O)-A, R-S-C(S)-O-A, where R is C₁ to C₂₀ substituted or non-substituted, straight chain, branched chain, cyclic, heterocyclic or aromatic alkyl;

A-B-X;





where: X = a halide, especially Cl or Br,

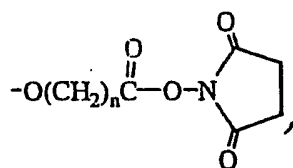
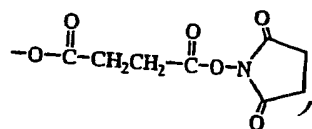
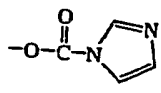
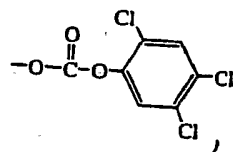
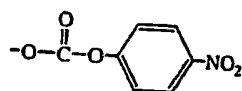
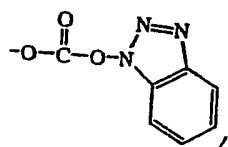
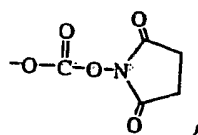
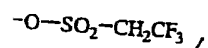
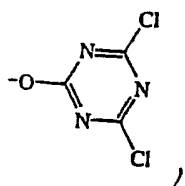
A = a moiety which, when attached to the comb polymer, is capable of binding
to a protein or polypeptide;

B is a linker and may or may not be present.

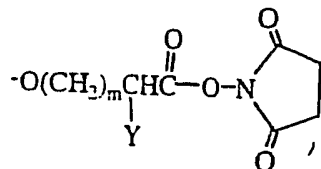
15. A method according to claim 14, wherein A is selected from succinimidyl succinate, N-hydroxy succinimide, succinimidyl propionate, succinimidyl butanoate, triazine, vinyl sulfone, propionaldehyde, acetaldehyde, tresylate, benzotriazole carbonate, maleimide, pyridyl sulfide, iodoacetamide and succinimidyl carbonate.

16. A method according to claim 14 or claim 15, wherein the linker, where present, is selected from a C₁ to C₂₀ substituted or non-substituted, straight chain, branched chain cyclic, heterocyclic or aromatic alkyl group; $-(CH_2Z)_aCH_2-$, $-CH_2ZCH_2-$, $-(CH_2CH_2Z)_n-R$, $-(CH_2CH(CH_3)Z)_n-R$, $-(CH_2)_b-C(O)-NH-(CH_2)_c-$, $-(CH_2)_a-NH-C(O)-(CH_2)_y-$, $-N(R)_2-$; $-S-$; $-N-R$; or $-O-R$; where R = C₁ to C₂₀ substituted or non-substituted, straight chain, branched chain cyclic, heterocyclic or aromatic alkyl, Z is O or S, and n, a, b and c are independently selectable integers between 1 and 10.

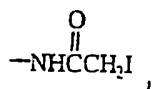
17. A method according to any one of claims 14 to 16, wherein the moiety which is capable of reacting with a protein or polypeptide has a formula:

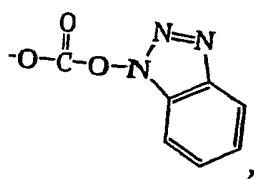
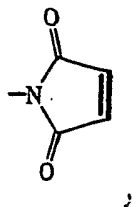
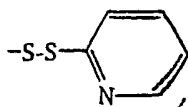


where n = integer of 0 to 10

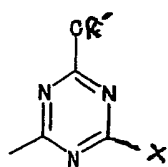


where m = integer of 0 to 10, Y is an aliphatic or aromatic moiety



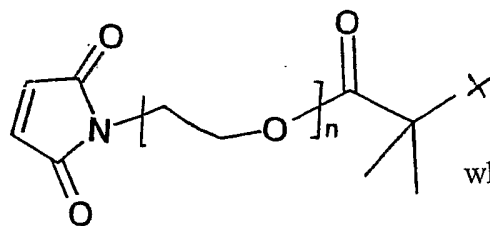
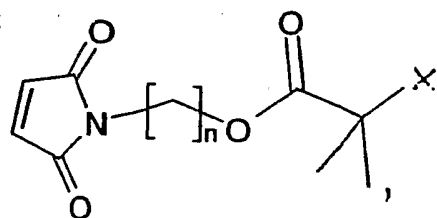


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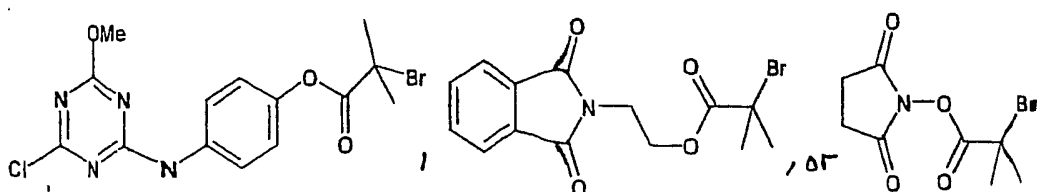
where R' is H, methyl, ethyl, propyl or butyl, X = halide.

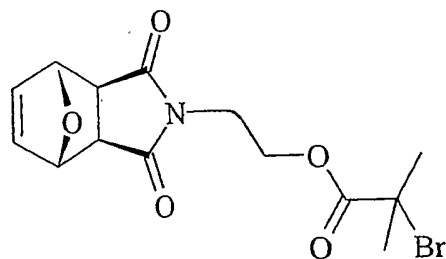
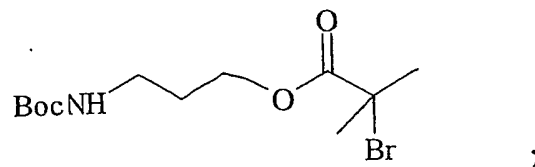
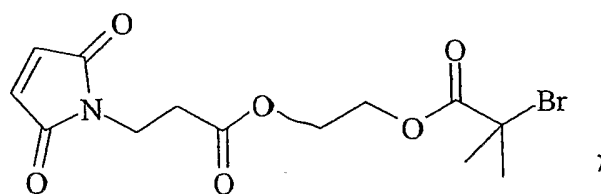
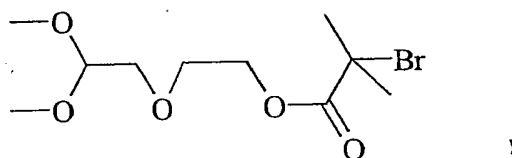
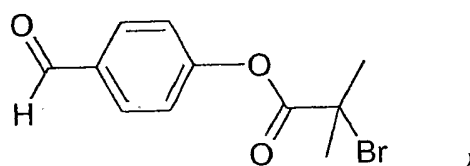
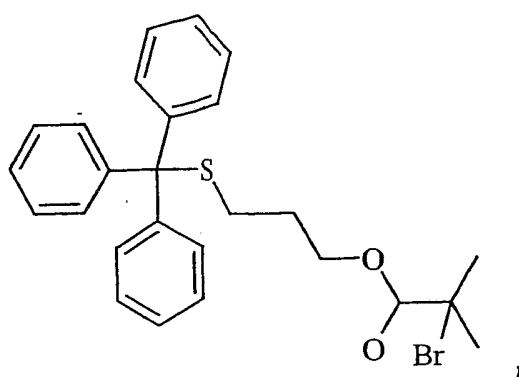
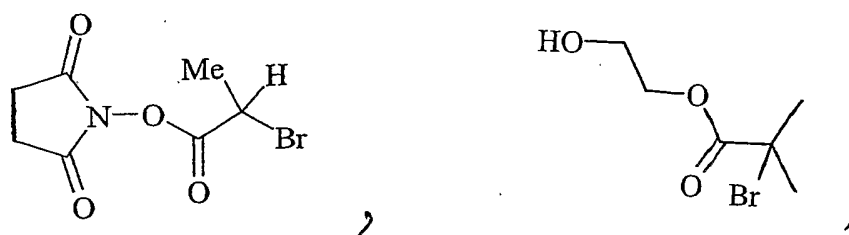
18. A method according to any one of claims 14 to 17, wherein the initiator (ii) has a formula:



where n is an integer of 0 to 10, and X is a halide.

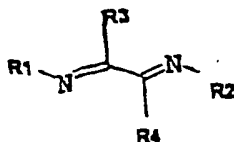
19. A method according to any preceding claim, wherein the initiator has a formula:



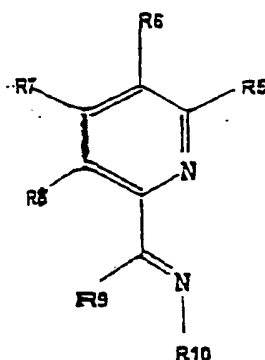


20. A method according to any one of claims 7 to 19, wherein the organodiimine is selected from:

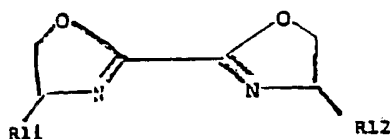
a 1,4-diaza-1,3-butadiene



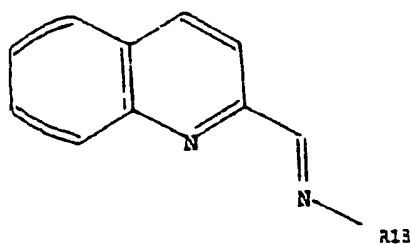
a 2-pyridine carbaldehyde imine



an oxazolidone.



or a quinoline carbaldehyde



where: R_1 , R_2 , R_{10} , R_{11} , R_{12} and R_{13} are independently selectable and may be selected from H, straight chain, branched chain or cyclic saturated alkyl, hydroxyalkyl, carboxyalkyl, aryl, CH_2 Ar (where Ar is aryl or substituted aryl) or a halogen;

R_3 to R_9 are independently selectable and may be selected from H, straight chain, branched chain or cyclic alkyl, hydroxyalkyl, carboxyalkyl, aryl, CH_2 Ar, a

halogen. OCH_{2n+1} (where n is an integer of 1 to 20), NO_2 , CN , $\text{O} = \text{CR}$ (where $\text{R} =$ alkyl, aryl, substituted aryl, benzyl PhCH_2 or a substituted benzyl)

21. A method according to claim 20, wherein the organodiimine is N-(n-propyl)-2-pyridylmethanimine (NMPI), N(n-ethyl)-2-pyridylmethanimine, or N-ethyl-2-pyridylmethanimine.

22. A method according to claims 1 to 6, wherein the catalyst comprises a bipyridine group.

23. A method according to claim 22 wherein the catalyst is 4,4'-di(5-nonyl)-2,2'-bipyridyl (dNbpy).

24. A method according to any preceding claim, comprising the use of a plurality of different monomers as defined in part (i) of claim 1.

25. A method according to any preceding claim, additionally comprising the step of producing a block co-polymer of the monomers as defined in part (i) of claim 1, with one or more different olefinically unsaturated monomers.

26. A method according to claim 25, wherein the comb polymer comprising the monomers as defined in part (i) of claim 1 are polymerised with the initiator (ii) and catalyst (iii), prior to the addition of the one or more different olefinically unsaturated monomers.

27. A method according to claim 25, wherein the one or more different olefinically unsaturated monomers are polymerised with the initiator (ii) and catalyst (iii), prior to the polymerisation of the monomers as defined in part (i) of claim 1.

28. A method according to any one of claims 25 to 27, wherein the one or more different olefinically unsaturated monomers are selected from methylmethacrylate, butylmethacrylate, acrylate, methacrylate and styrene.

29. A method according to any preceding claim in which the reactants are reacted in a hydrophobic or hydrophilic solvent.

30. A method according to claim 29, in which the solvent is selected from water, propionitrile, hexane, heptane, dimethoxyethane, diethoxyethane, tetrahydrofuran, ethylacetate, diethylether, N,N-dimethylformamide, anisole, acetonitrile, diphenylether, methylisobutyrate, butan-2-one, toluene and xylene.

31. A method according to any preceding claim in which the polymerisation reaction is carried out at -20 to 200°C.

32. A method according to any preceding claim in which the catalyst is a supported catalyst.

33. A method according to any preceding claim, additionally comprising the step of copolymerising or block polymerising with at least one fluorescently labelled monomer capable of undergoing additional polymerisation.

34. A method according to claim 33, wherein the fluorescent label is a coumarin.

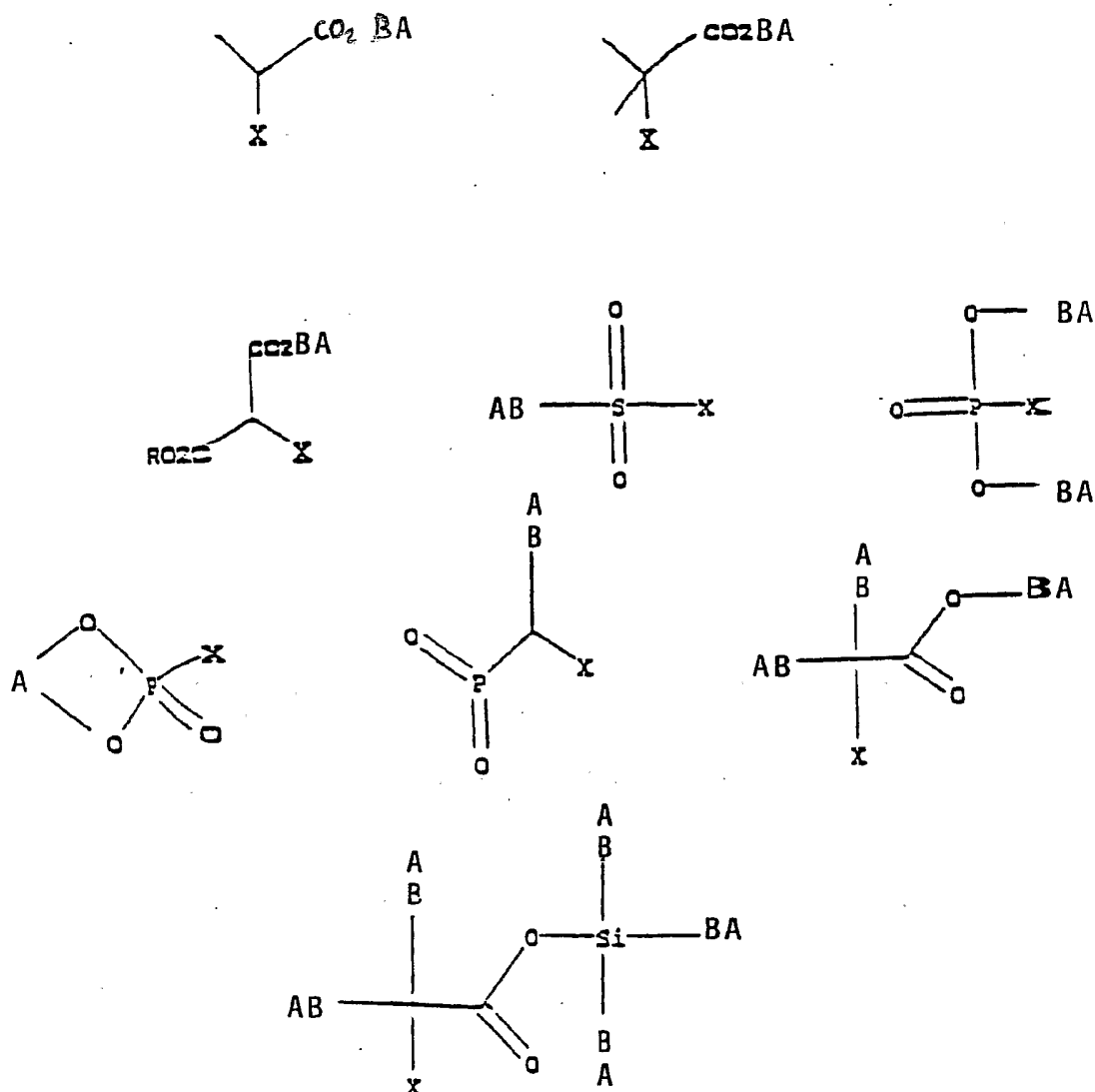
35. An initiator compound capable of being used in a living radical polymerisation reaction comprising a moiety which, when attached to a polymer is capable of binding to a protein or polypeptide.

36. An initiator for use in a living radical polymerisation reaction having a formula selected from:

A-S-C(O)-R, A-S-C(S)-O-R, R-S-C(O)-A, R-S-C(S)-O-A, where R is C₁ to C₂₀ substituted or non-substituted, straight chain, branched chain, cyclic, heterocyclic or aromatic alkyl;

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A-B-X;



where: X = a halide, especially Cl or Br,

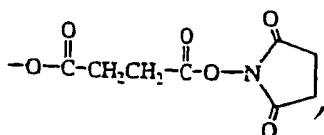
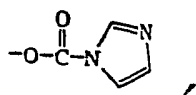
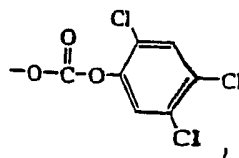
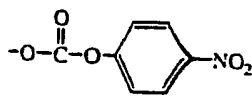
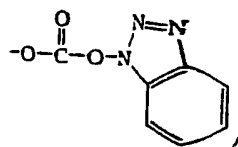
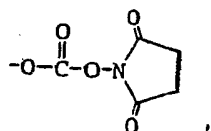
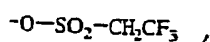
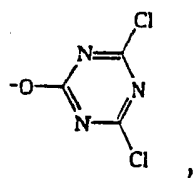
A = a moiety which, when attached to the comb polymer, is capable of binding to a protein or polypeptide,

B is a linker **and** may or may not be present.

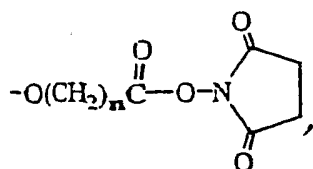
37. An initiator according to claim 35 or claim 36, wherein A is selected from succinimidyl succinate, N-hydroxy succinimide, succinimidyl propionate, succinimidyl butanoate, propionaldehyde, acetaldehyde, tresylate, benzotriazole carbonate, maleimide, triazine, vinyl sulfone, pyridyl sulfide, iodoacetamide and succinimidyl carbonate.

38. An initiator according to any one of claims 35 to 37, wherein the linker, where present, is selected from a C_1 to C_{20} substituted or non-substituted, straight chain, branched chain cyclic, heterocyclic or aromatic alkyl group; $-(CH_2Z)_aCH_2-$, $-CH_2ZCH_2-$, $-(CH_2CH_2Z)_n-R$, $-(CH_2CH(CH_3)Z)_n-R$, $-(CH_2)_b-C(O)-NH-(CH_2)_c-$, $-(CH_2)_a-NH-C(O)-(CH_2)_y-$, $-N(R)_2$; $-S-$; $-N-R$; or $-O-R$; where $R = C_1$ to C_{20} substituted or non-substituted, straight chain, branched chain cyclic, heterocyclic or aromatic alkyl, Z is O or S, and n , a , b and c are independently selectable integers between 1 and 10.

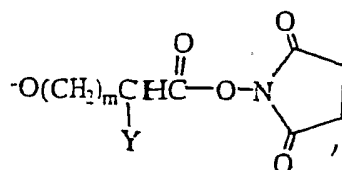
39. An initiator according to any one of claims 35 to 38, wherein the moiety which is capable of reacting with a protein or polypeptide has a formula:



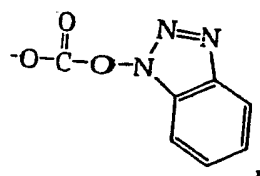
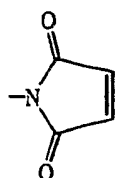
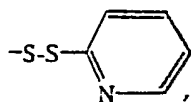
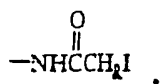
63



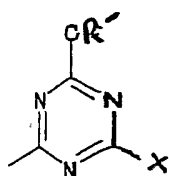
where n = integer of 0 to 10



where m = integer of 0 to 10, Y is an aliphatic or aromatic moiety

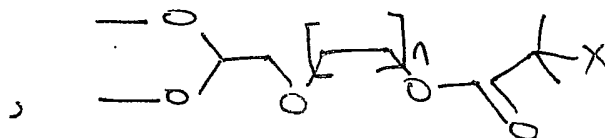
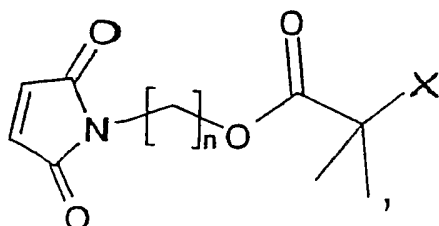


and



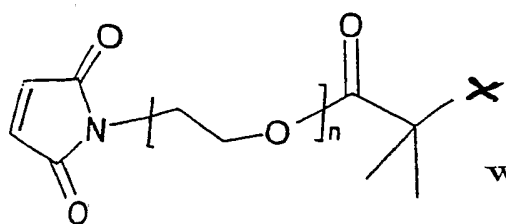
where R' is H, methyl, ethyl, propyl or butyl, X is a halide.

40. An initiator according to any one of claims 34 to 39 wherein the initiator has a formula:



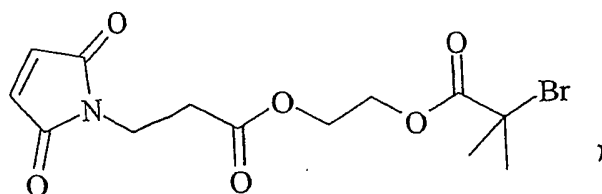
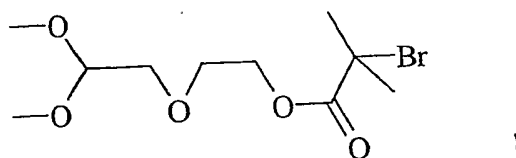
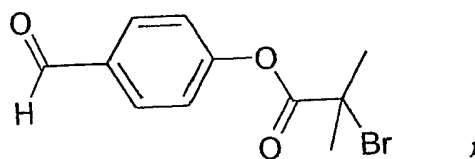
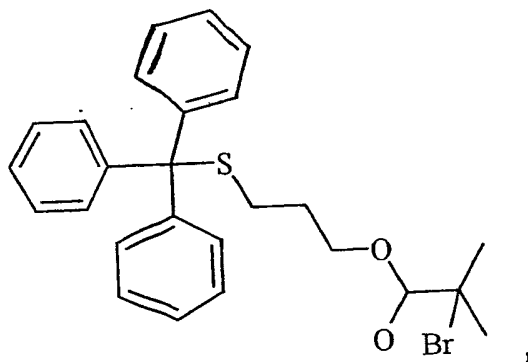
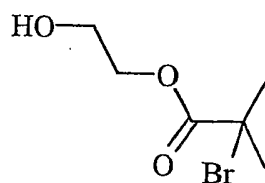
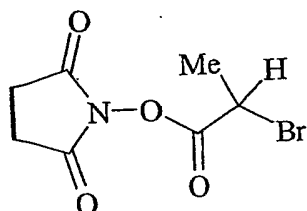
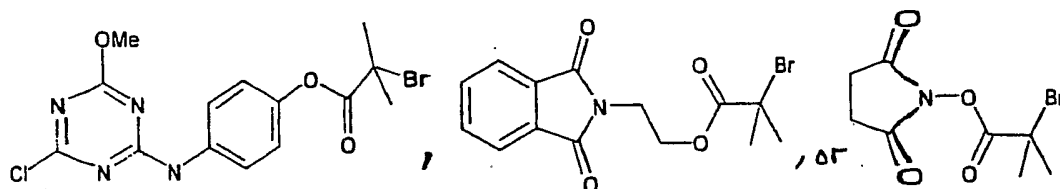
or

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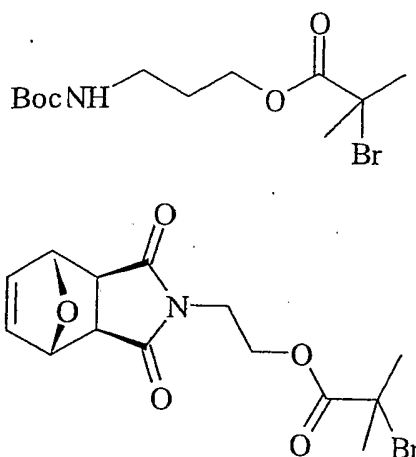


where n is an integer of 0 to 10, and X is a halide.

41. An initiator according to any one of claims 34 to 40 having the formula:

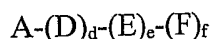


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42. A comb polymer capable of binding a protein or a polypeptide obtainable by a method according to any one of claims 1 to 33.

43. A comb polymer having a general formula:



where: A may or may not be present and is a moiety capable of binding to a protein or a polypeptide,

D, where present, is obtainable by additional polymerisation of one or more olefinically unsaturated monomers which are not as defined in E.

E is obtainable by additional polymerisation of a plurality of monomers which are linear, branched, or star-shaped substituted or non-substituted, and have an olefinically unsaturated moiety.

F, where present, is obtainable by additional polymerisation of one or more olefinically unsaturated monomers which are not as defined in E;

d and f are an integer between 0 and 500.

e is an integer of 0 to 1000;

wherein when A is present, at least one of D, E and F is present.

44. A comb polymer according to claim 43 wherein E is a poly(alkylene) glycol or polytetrahydrofuran.

45. A comb polymer according to claims 42 or 43 having an average molecular weight of 2,000 to 80,000.
46. A comb polymer according to any one of claims 42 to 45 which is fluorescently labelled.
47. A comb polymer according to claim 46, which is fluorescently labelled with a coumarin.
48. A method of attaching a polymer to a compound comprising reacting a comb polymer according to any one of claims 42 to 47 with said compound.
49. A compound obtainable by reacting a protein, polypeptide, thiol, carbohydrate, diamine and/or benzylamine-containing compound with a comb polymer according to any one of claims 42 to 47 to form a protein, polypeptide, thiol, amine and/or benzylamine-containing compound covalently attached to said comb polymer.
50. A compound according to claim 48 or claim 49 which is a protein or polypeptide, thiol and/or benzylamine-containing compound.
51. A compound according to any one of claims 48 to 50, which is biologically-active.
52. A compound according to claim 51, which is a drug.
53. A compound according to any one of claims 49 to 52 in combination with a pharmaceutically acceptable carrier.
54. A compound according to any one of claims 49 to 53, which is a cancer chemotherapeutic agent, an antibiotic, an anti-fungal and/or an immunosuppressant.

55. A compound according to claim 54 for use as a chemotherapeutic agent, an antibiotic, an anti-fungal agent and/or immunosuppressant.

56. The use of a compound according to claim 54 as a chemotherapeutic agent, an antibiotic, an anti-fungal agent and/or immunosuppressant.

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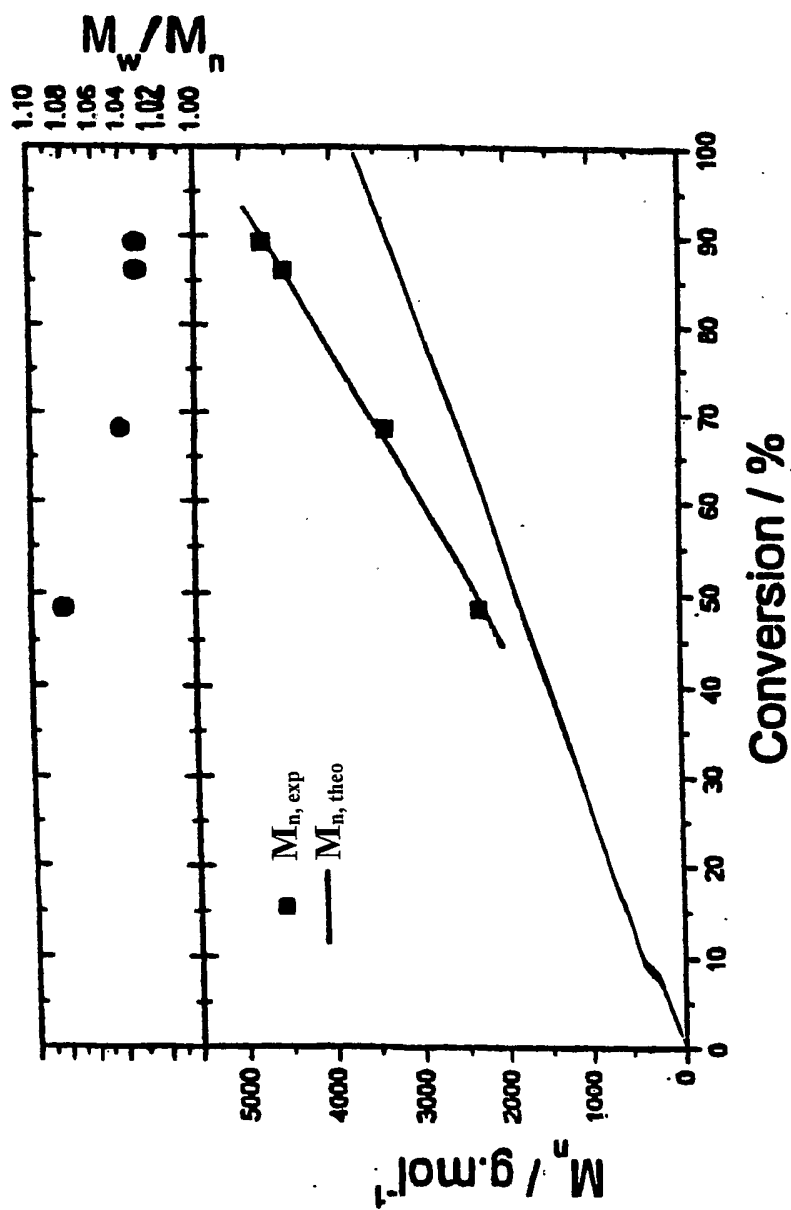


Figure 1.

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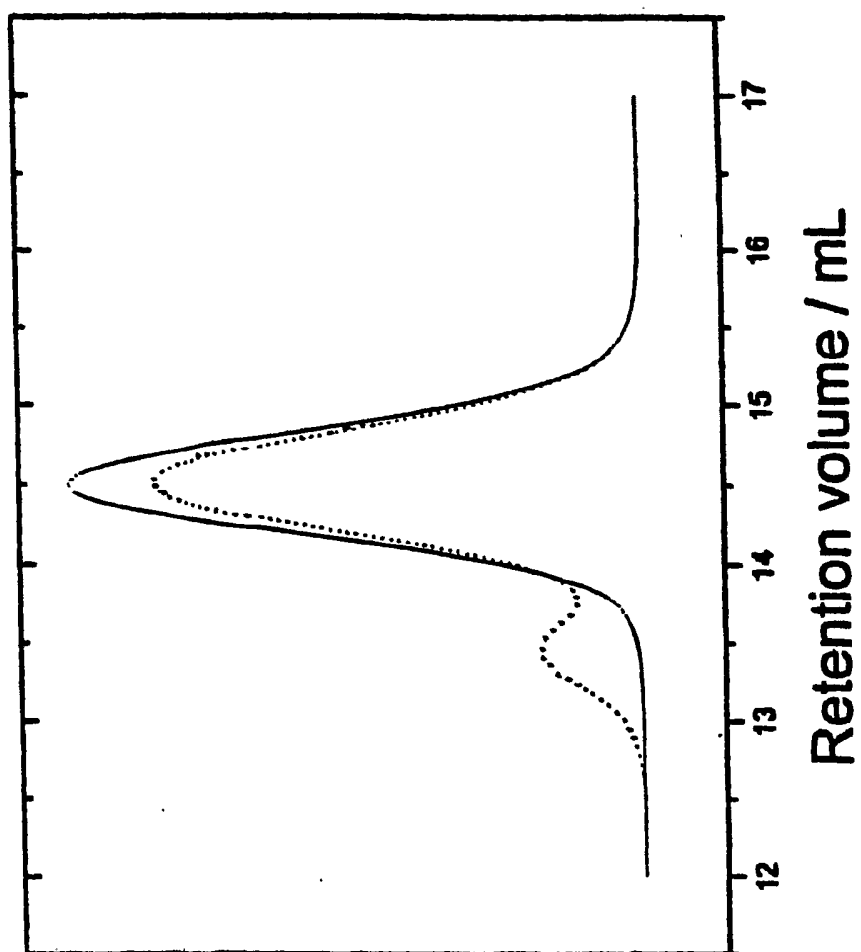


Figure 2.

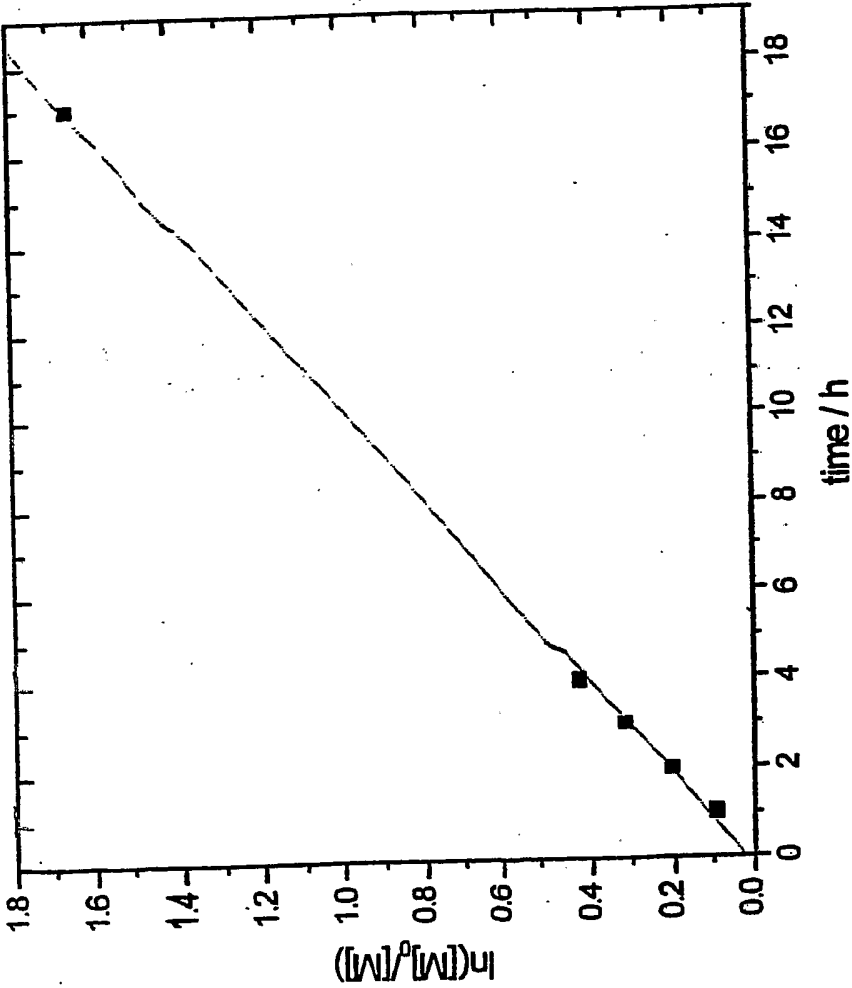


Figure 3.

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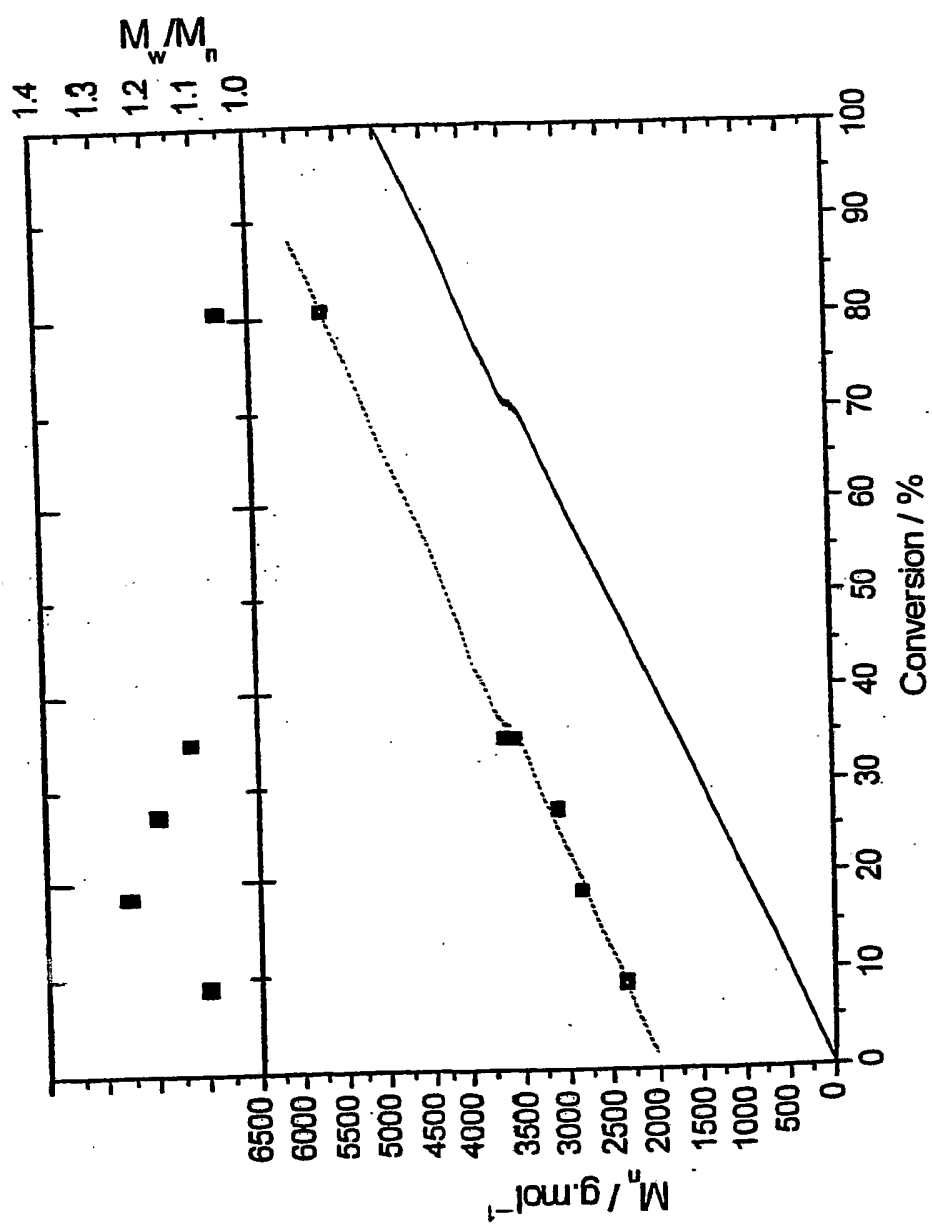


Figure 4.

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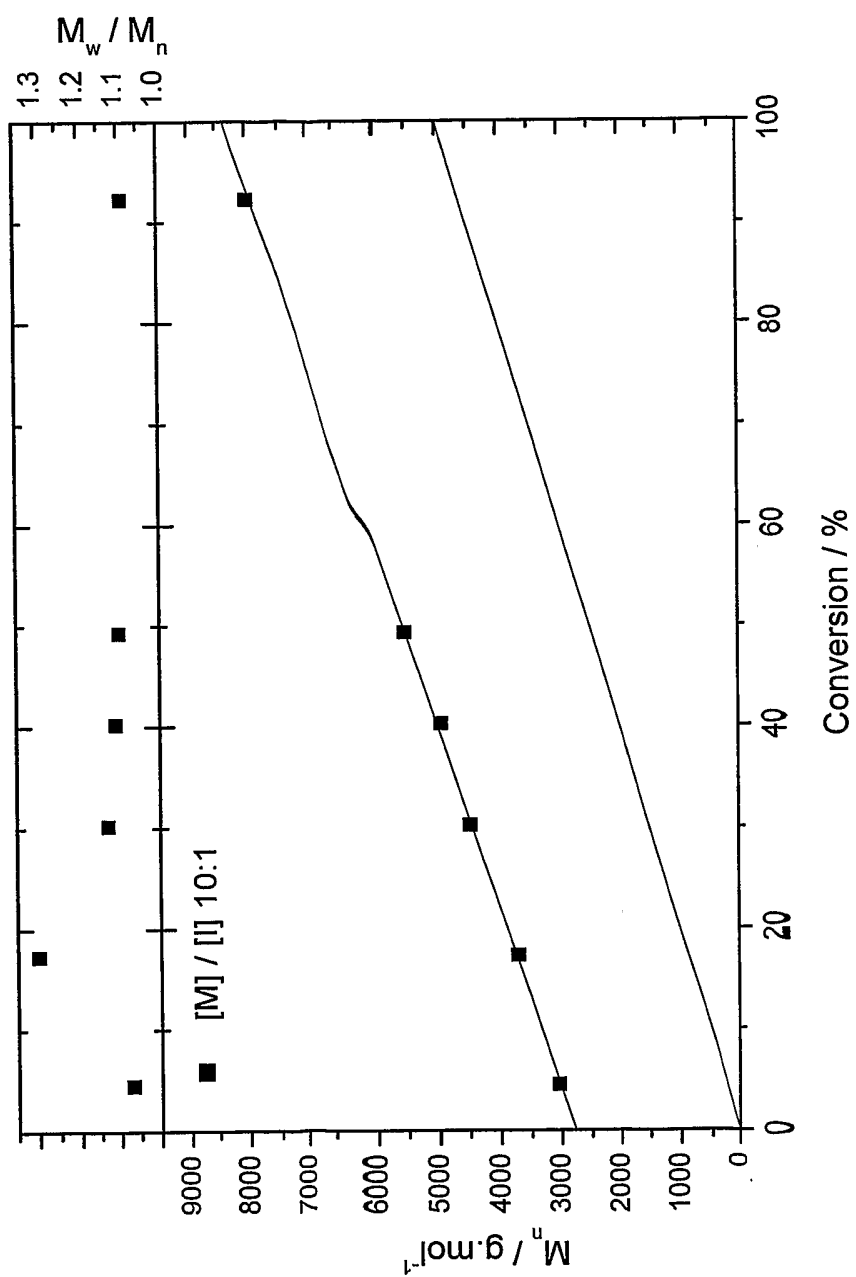


Figure 5.

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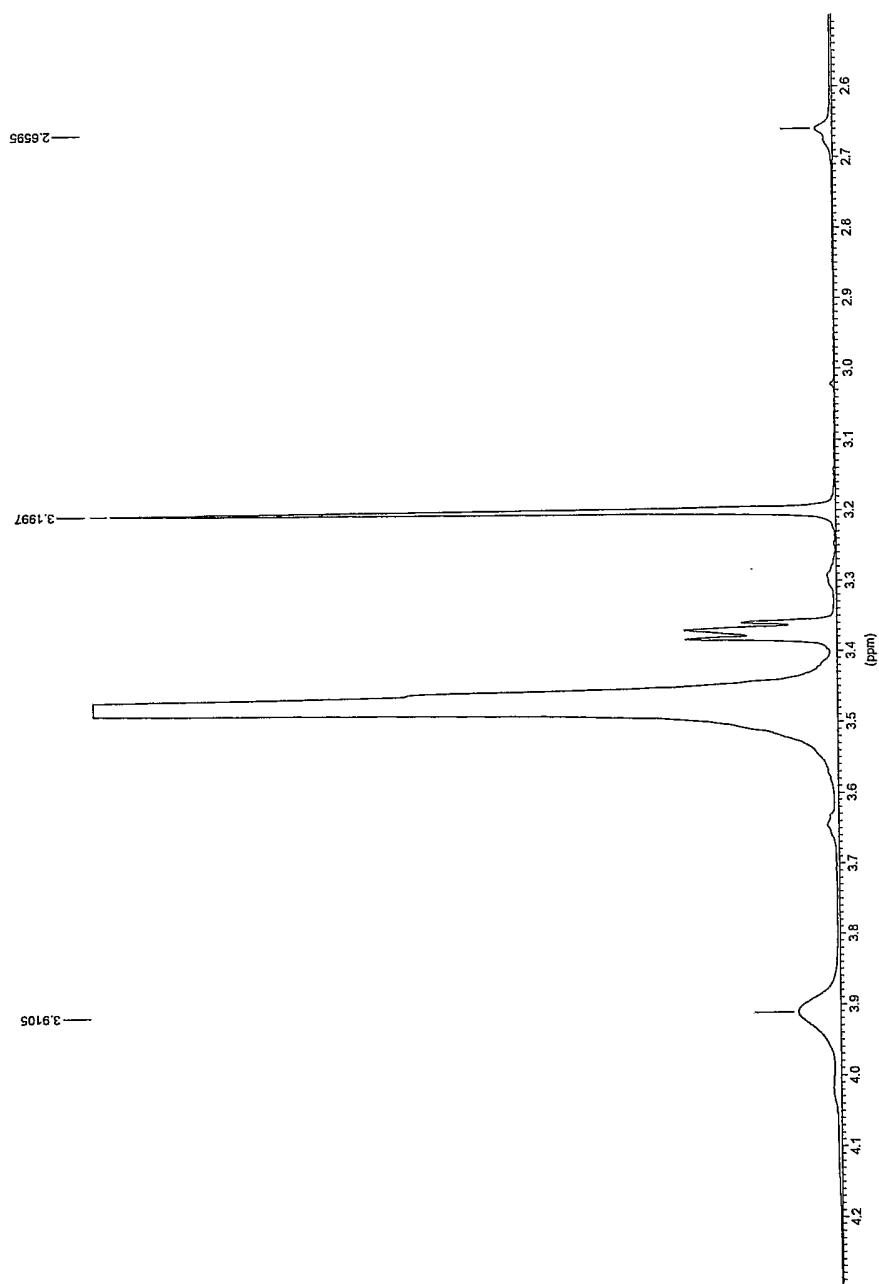


Figure 6.

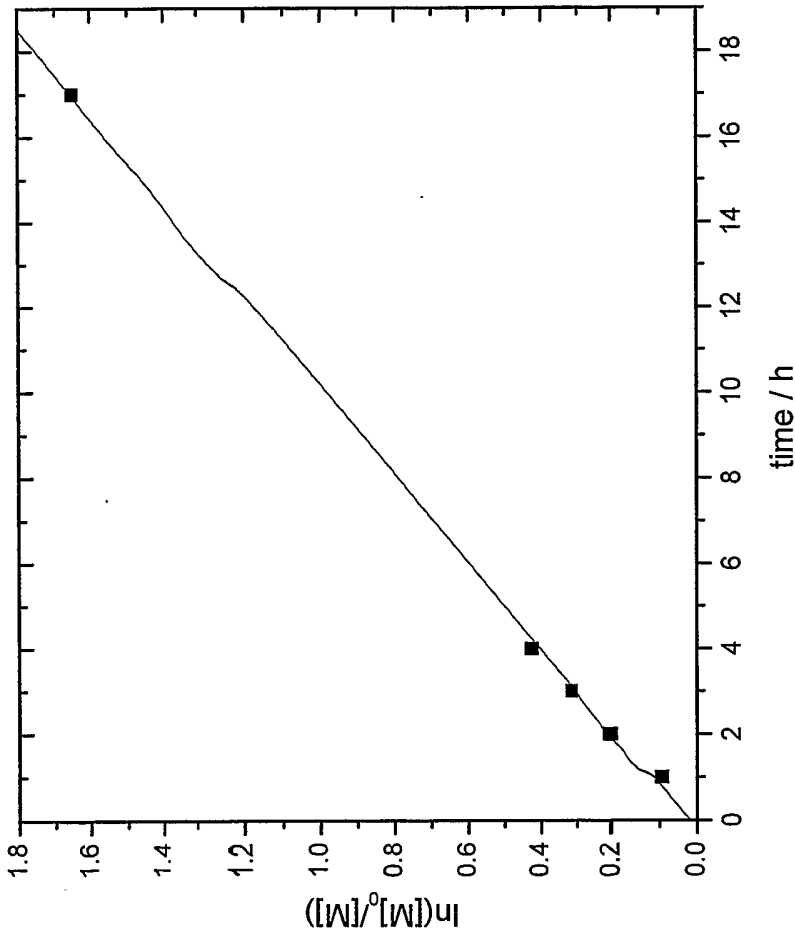


Figure 7.

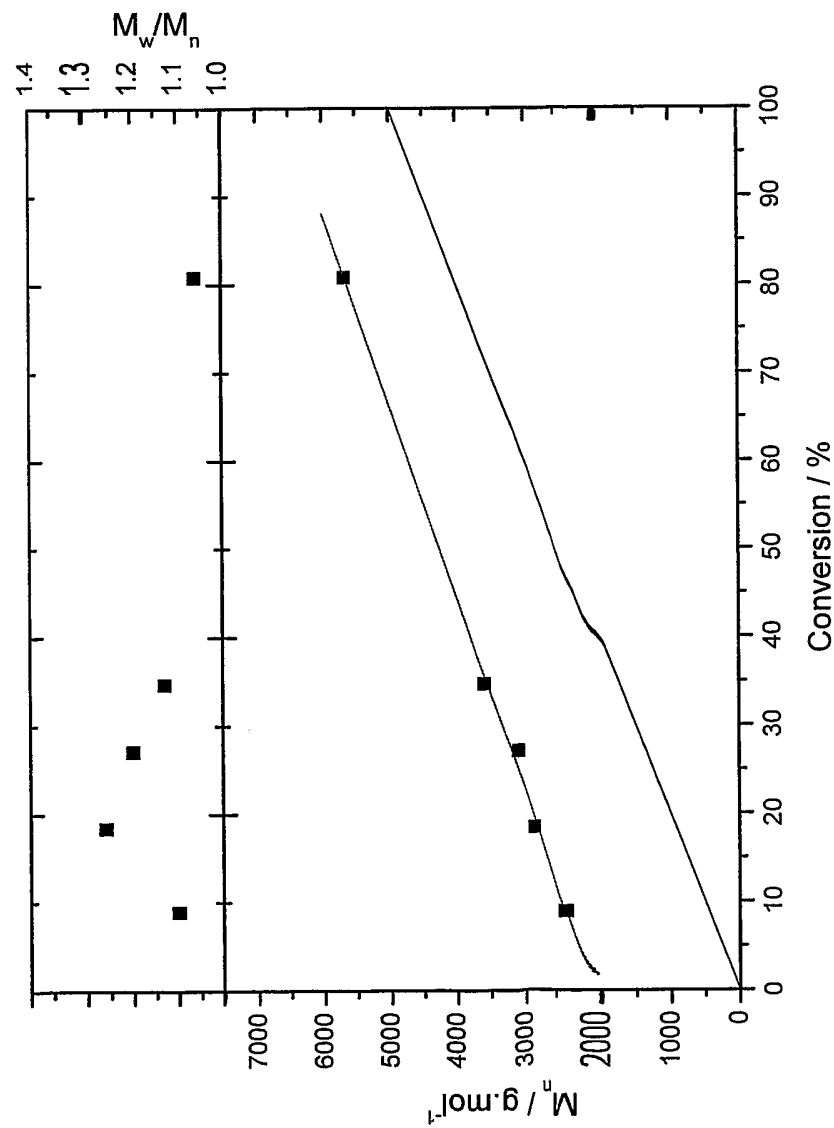


Figure 8.

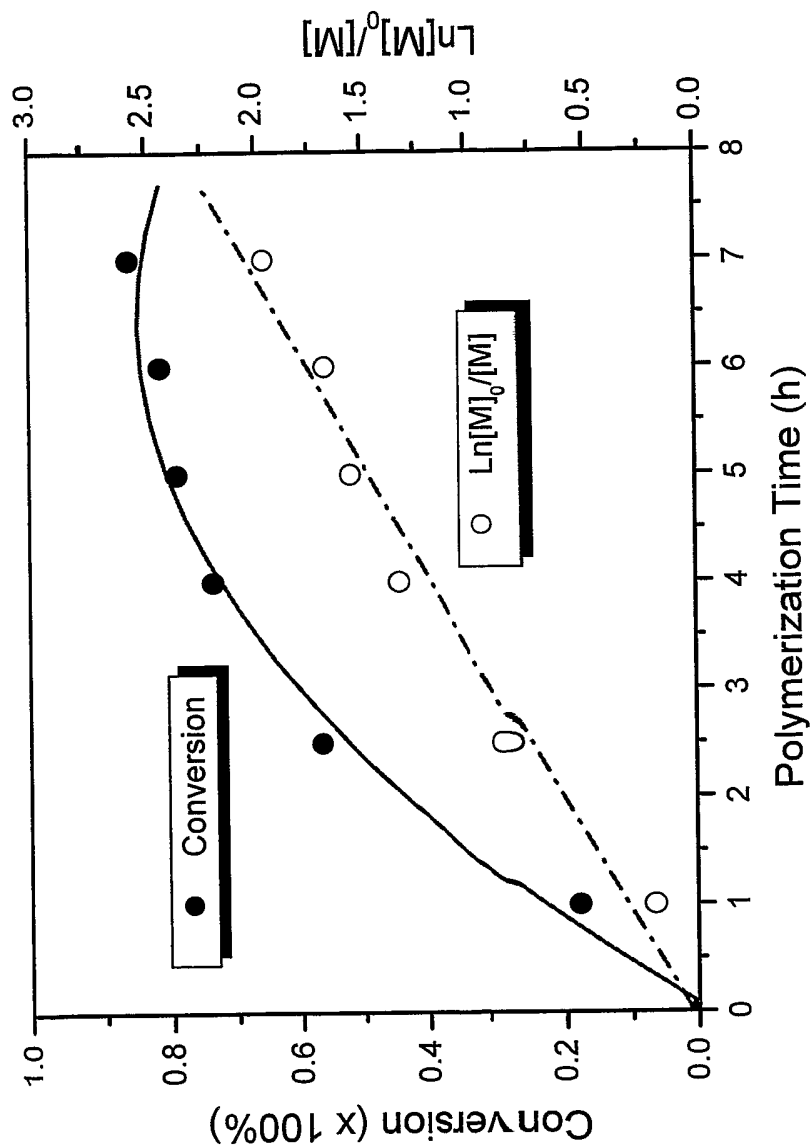


Figure 9.

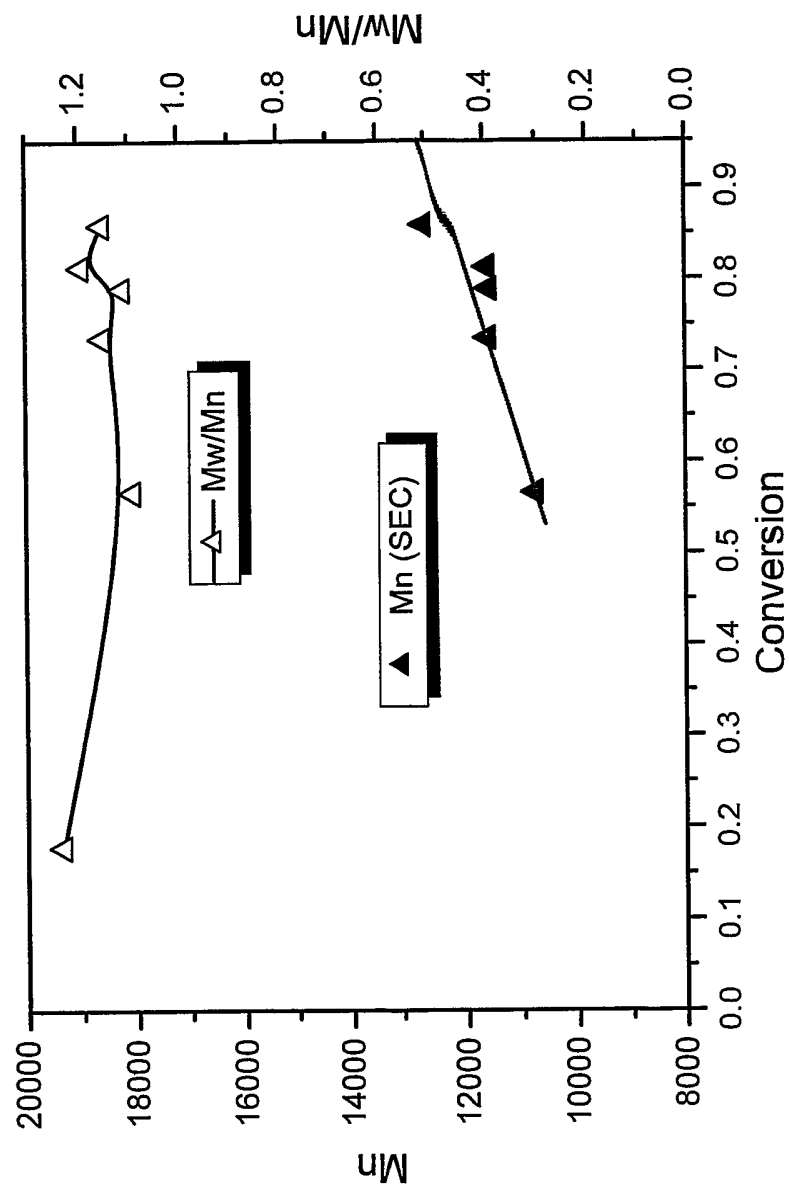


Figure 10.

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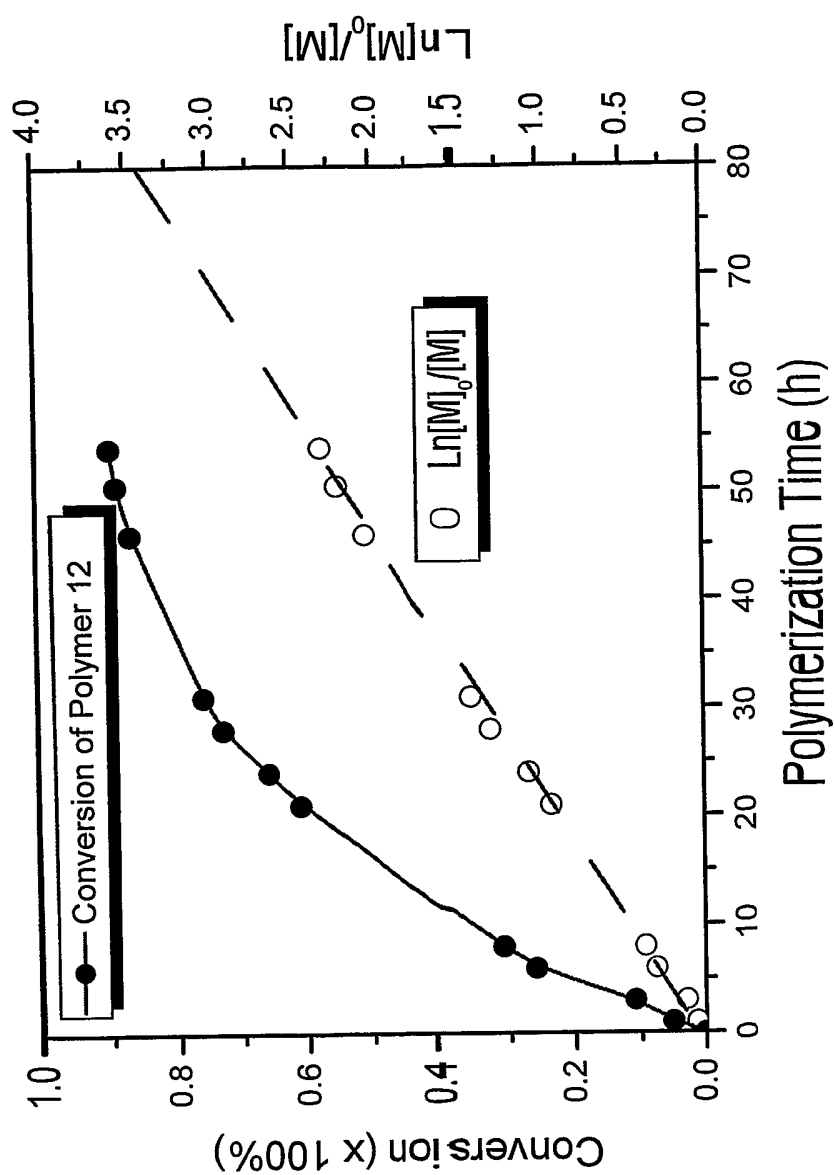
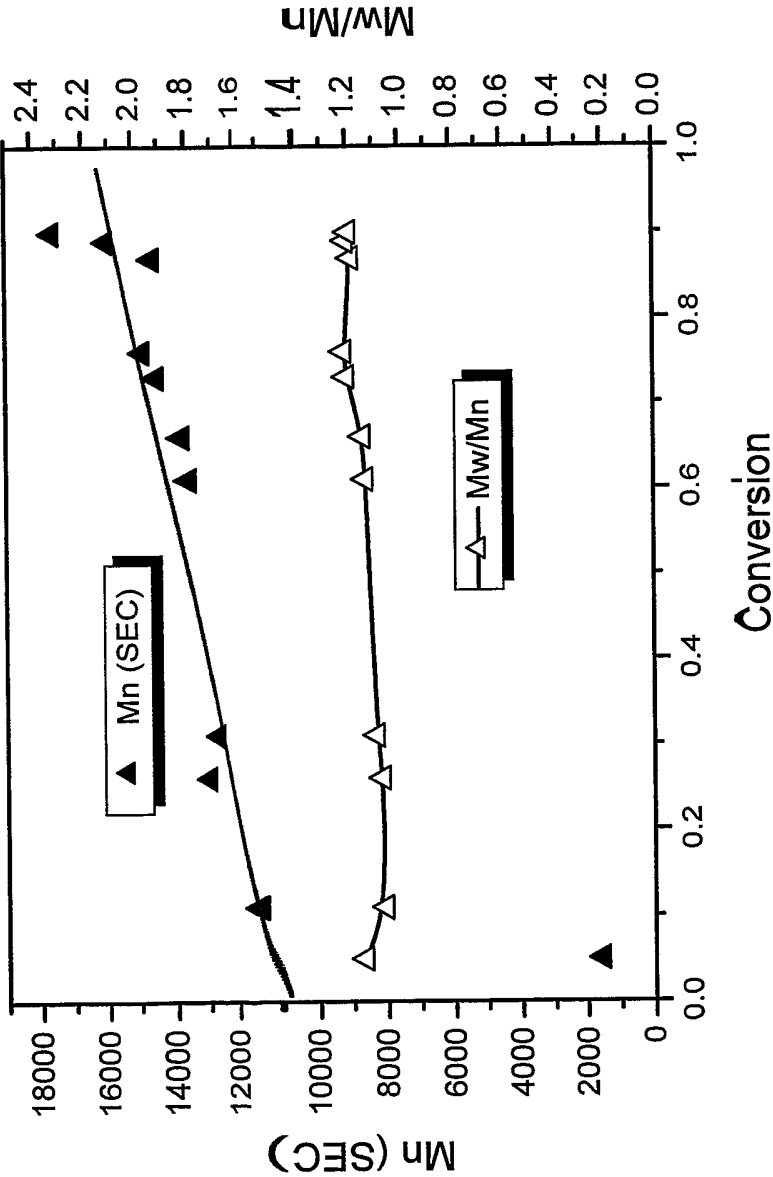


Figure 11.

Figure 12.



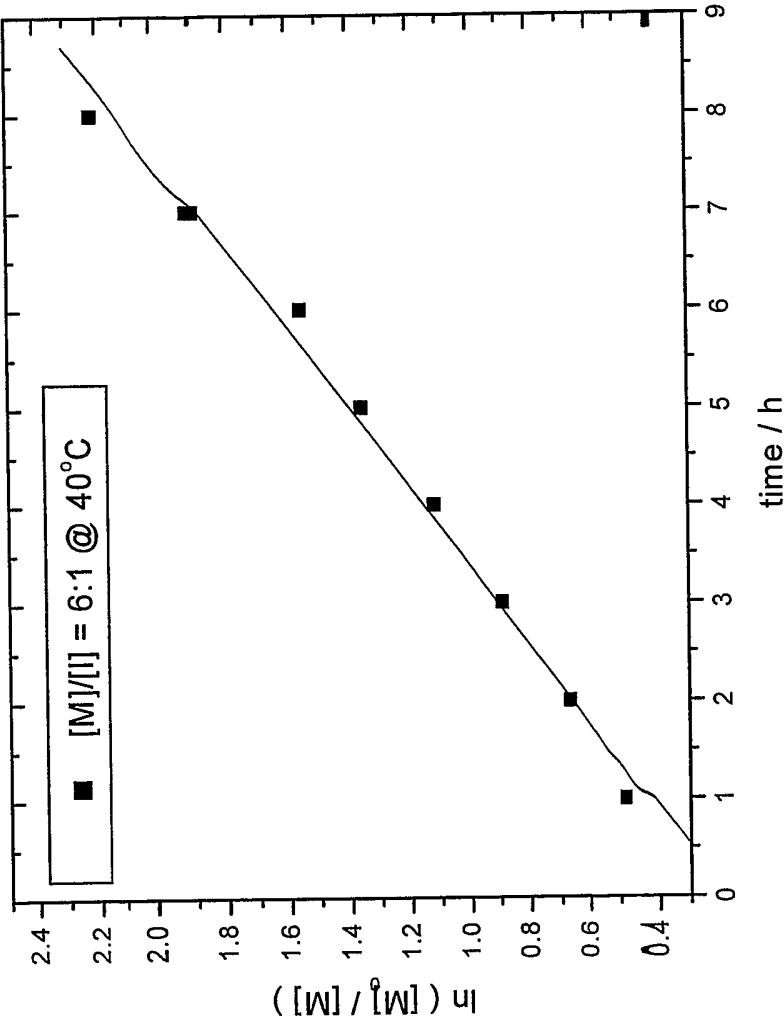
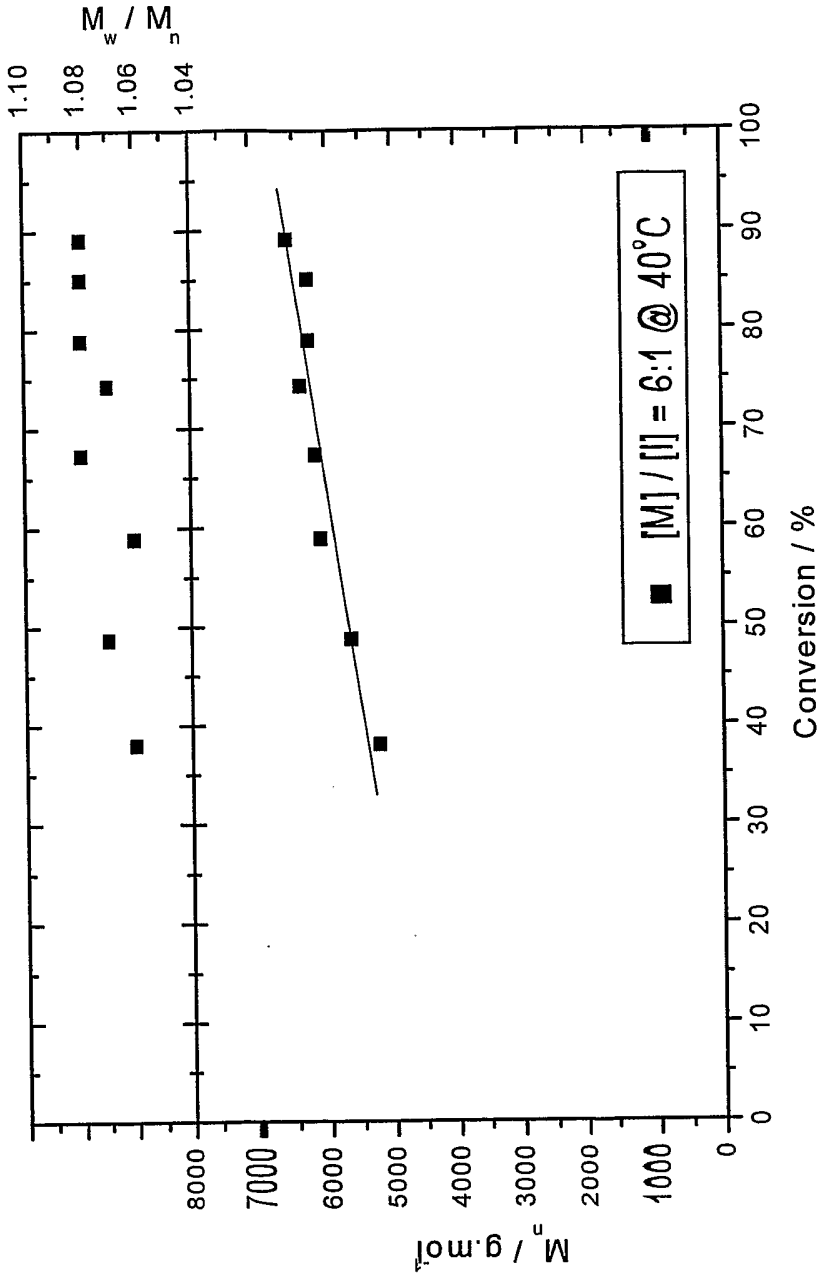


Figure 13.

Figure 14.



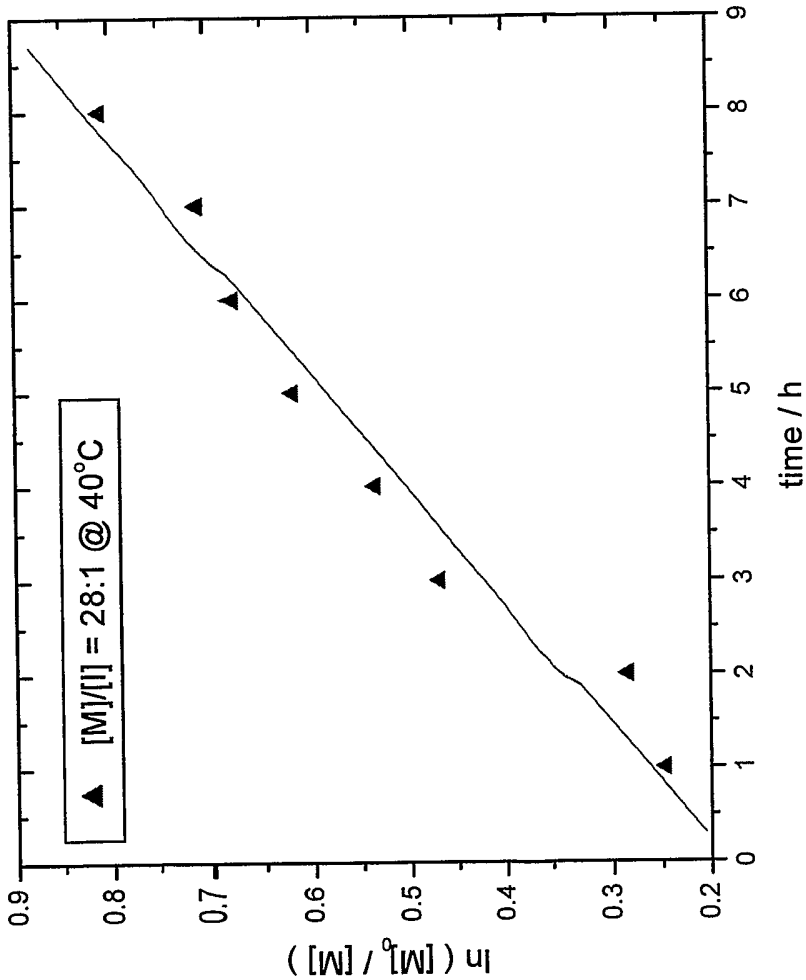


Figure 15.

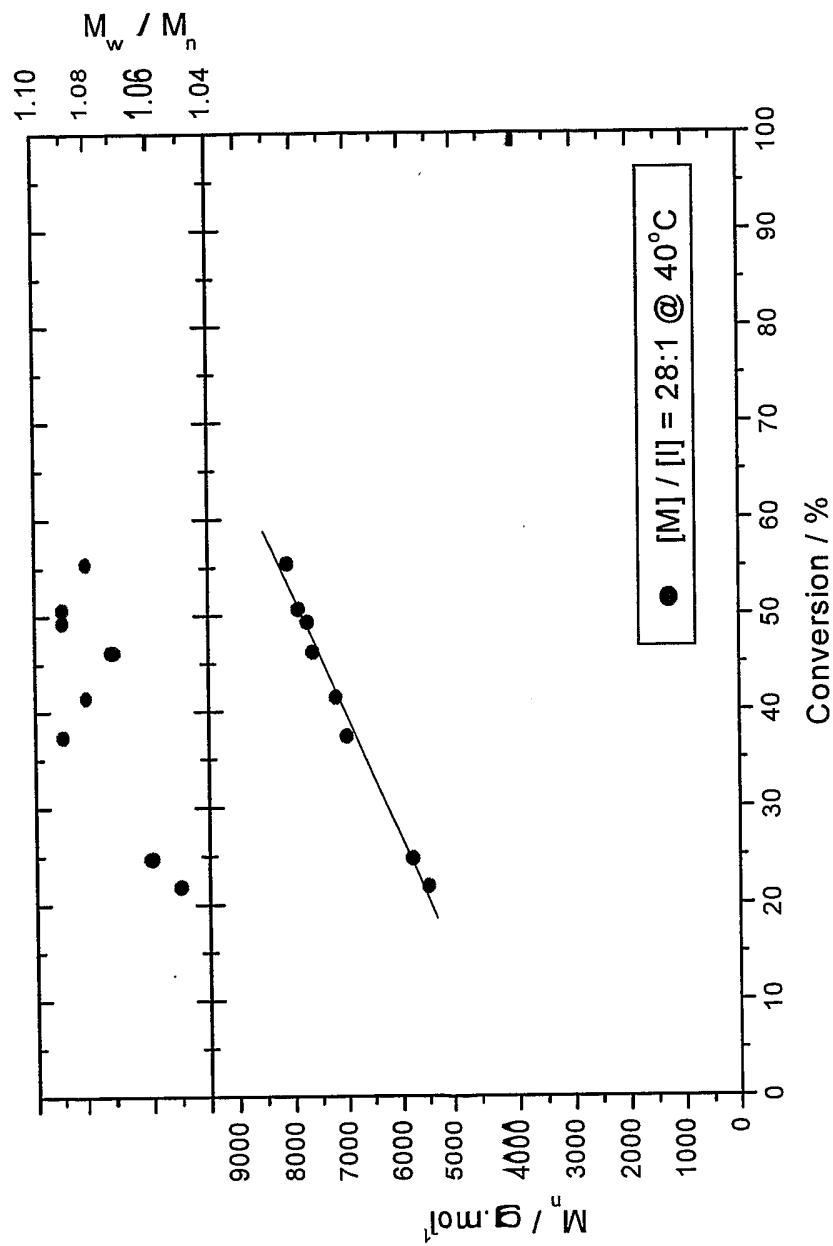


Figure 16.

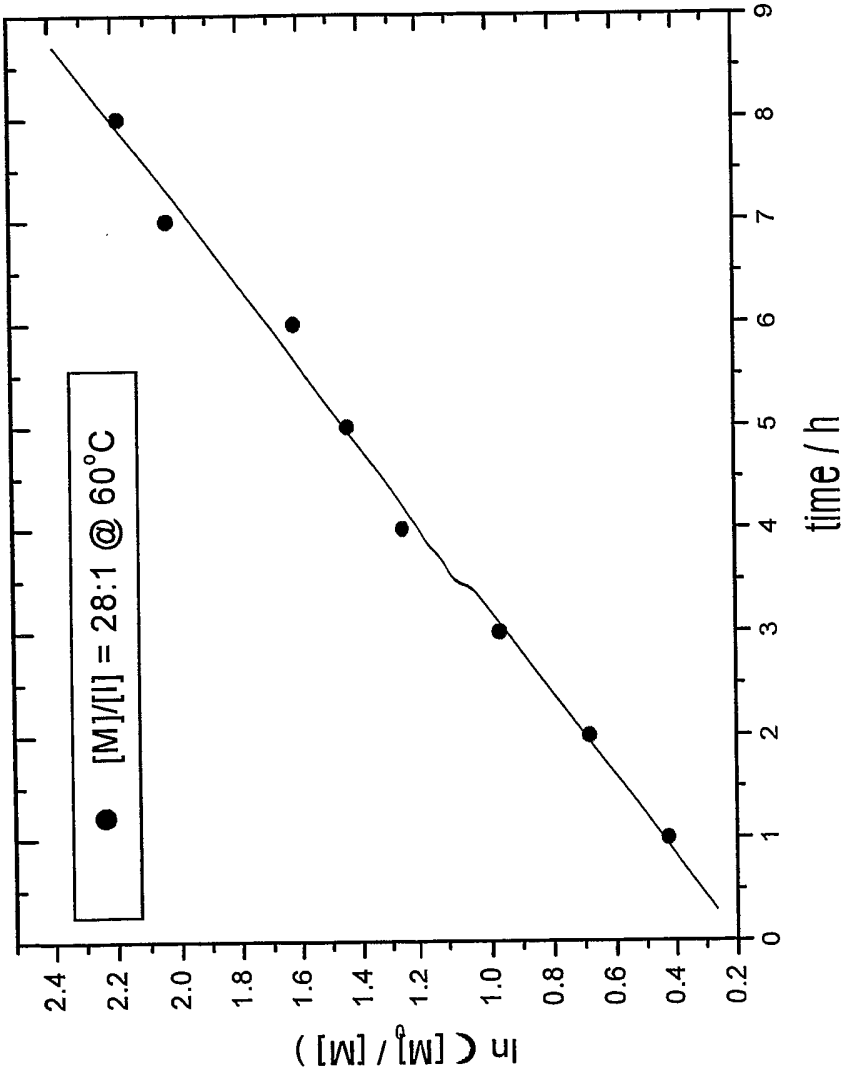


Figure 17.

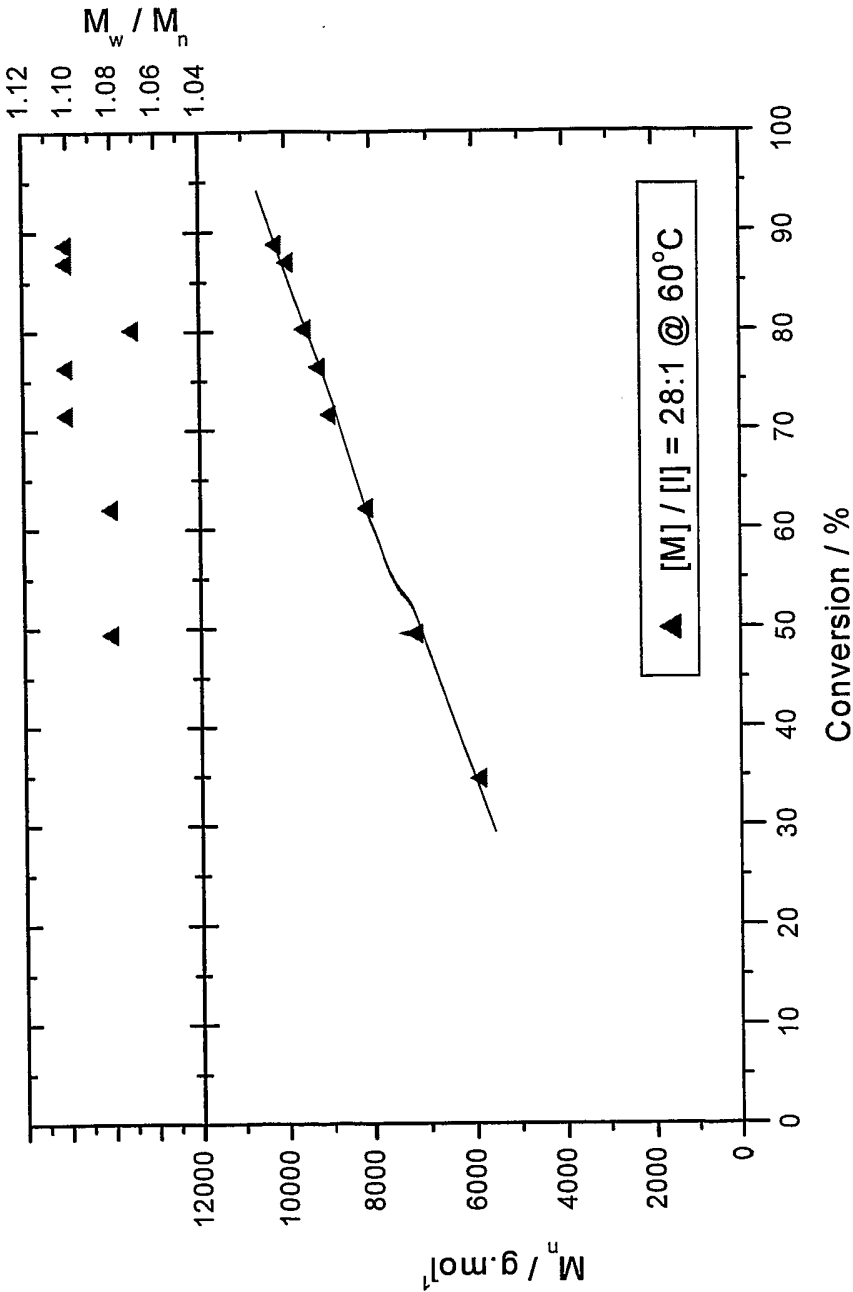


Figure 18.

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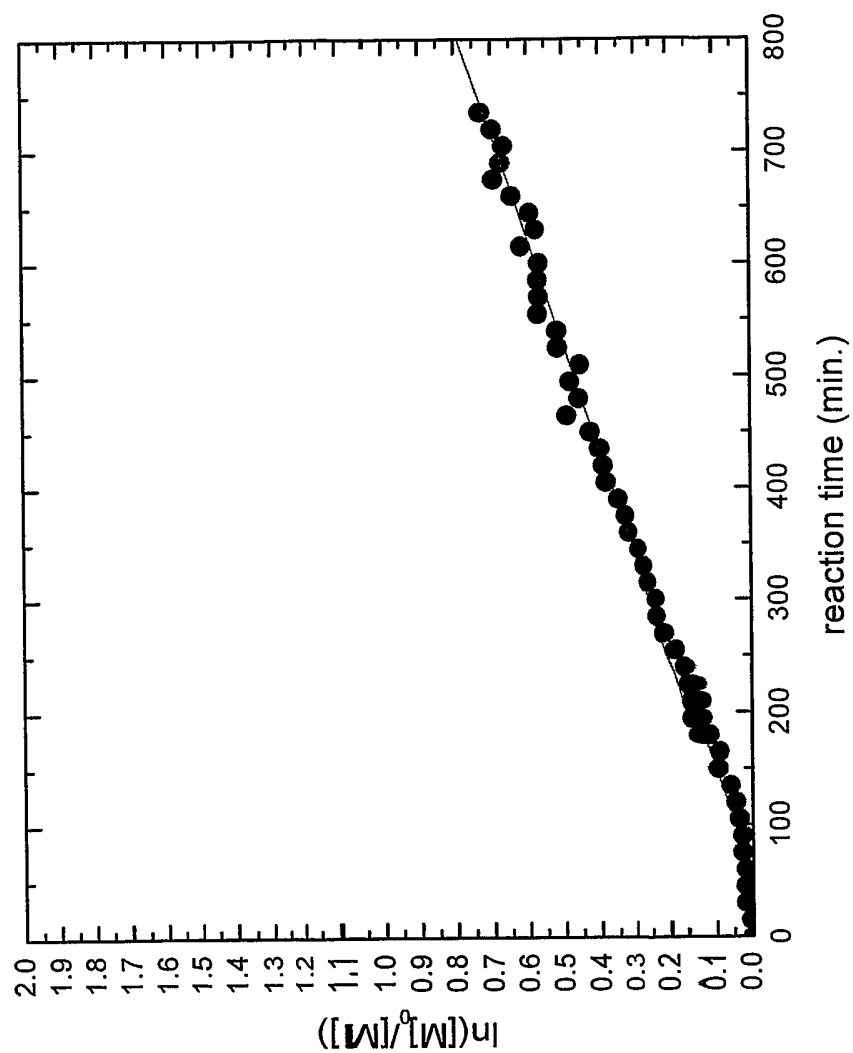


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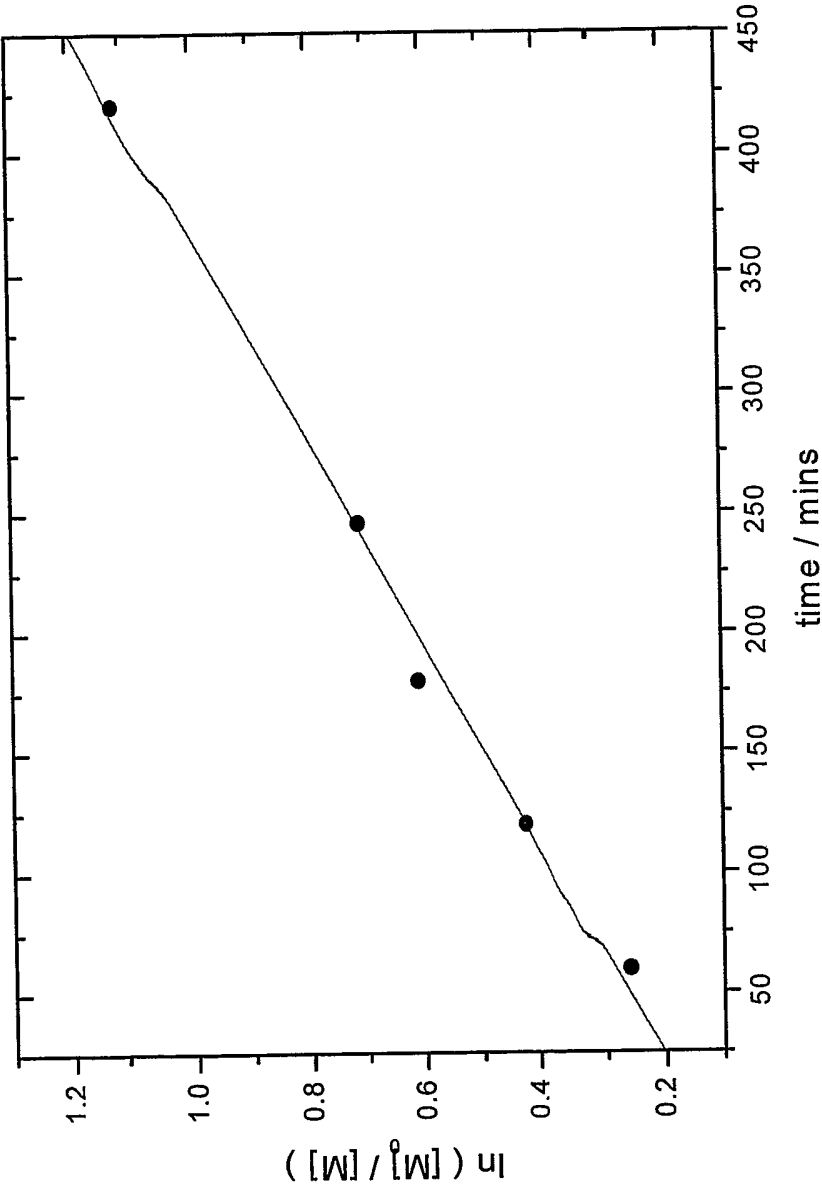


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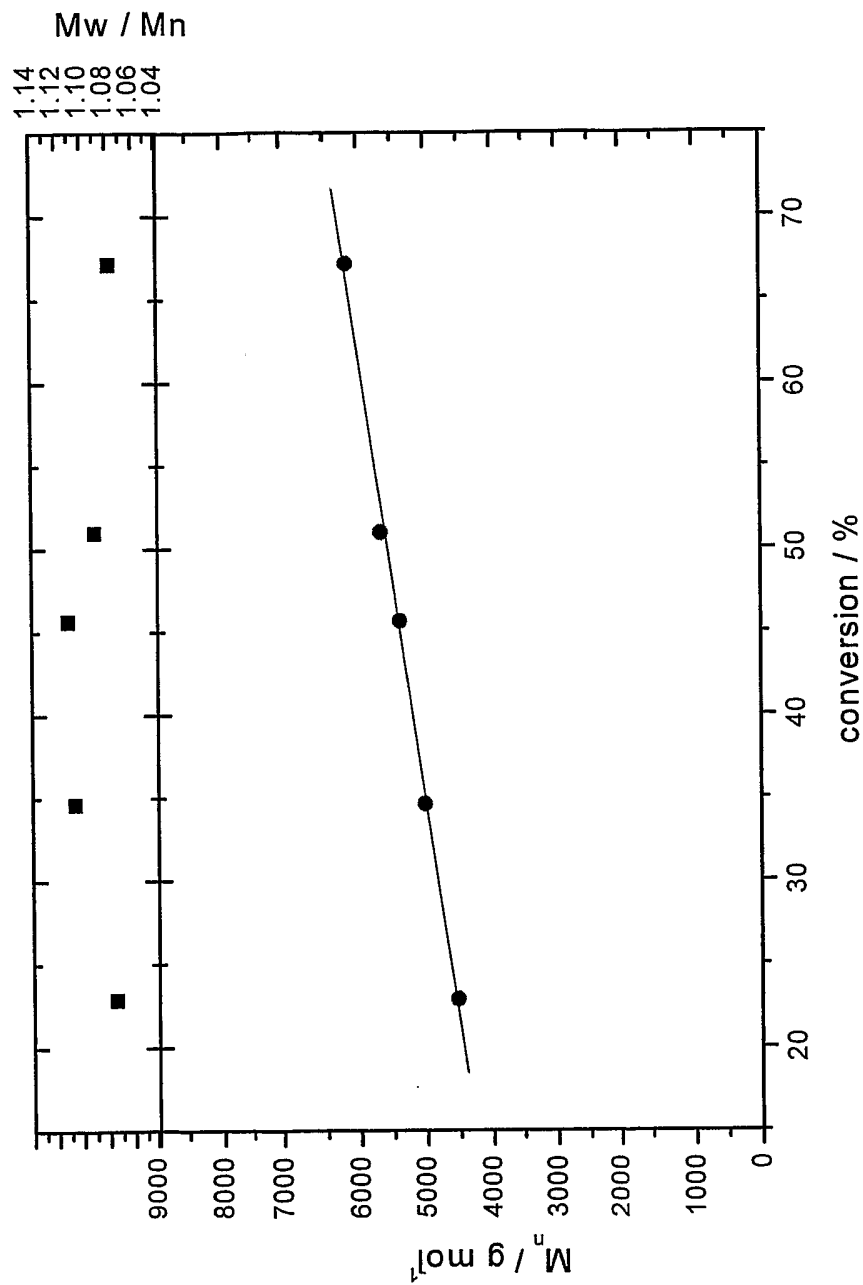


Figure 21.

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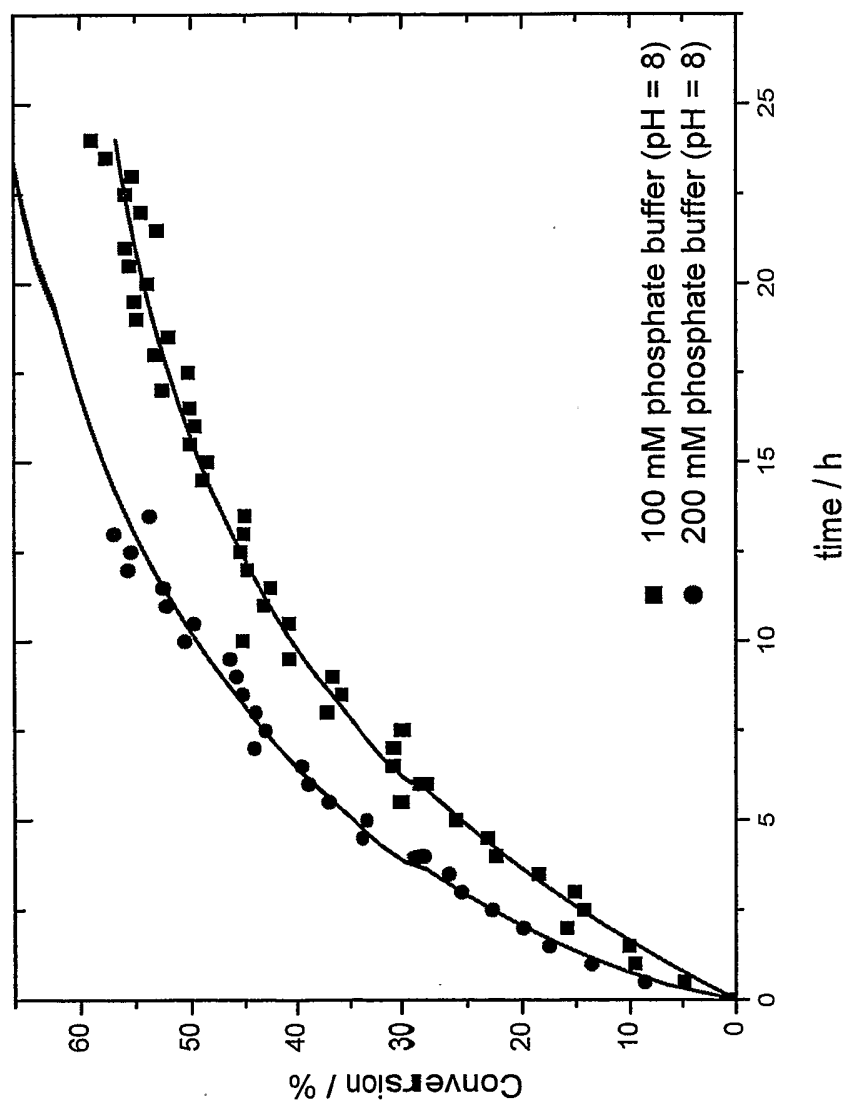


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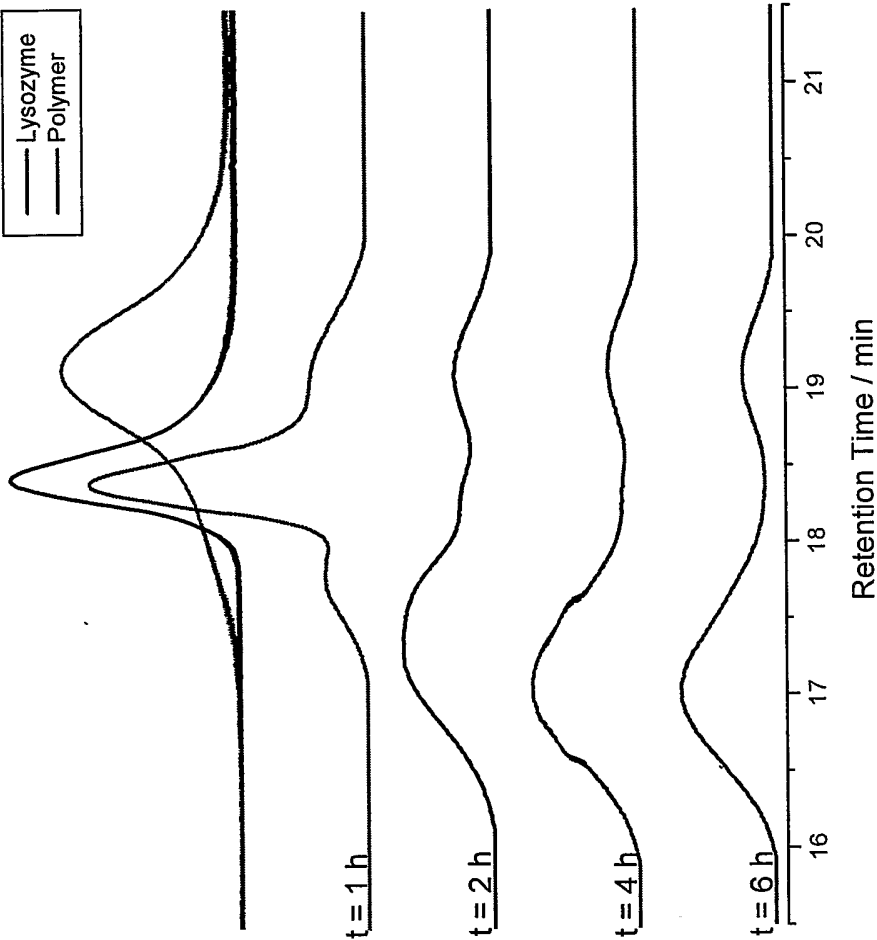


Figure 23.

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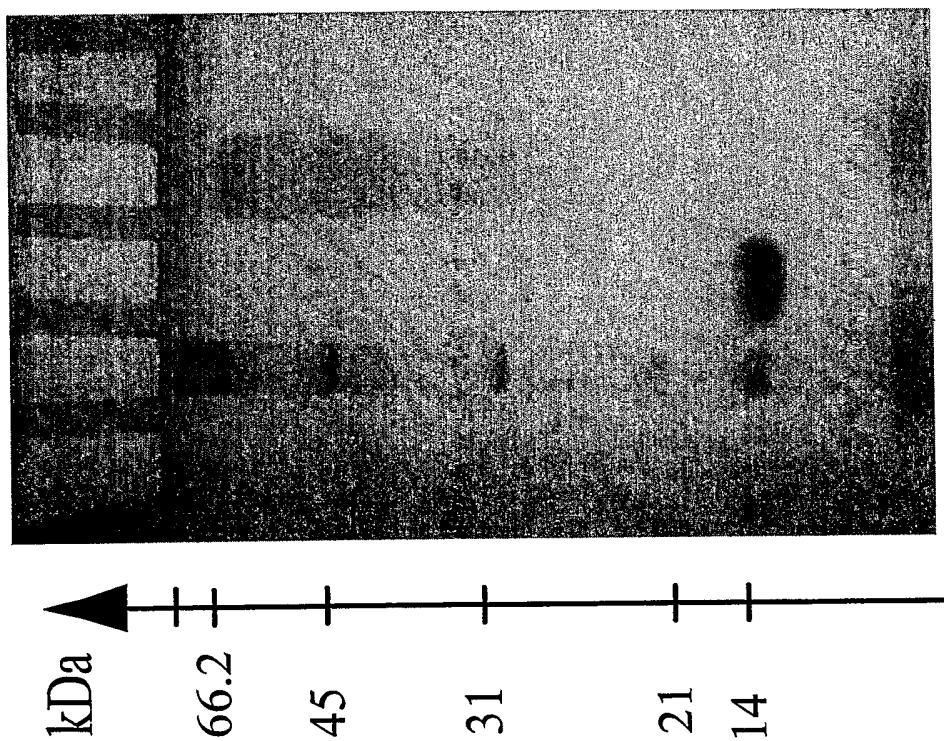


Figure 24.

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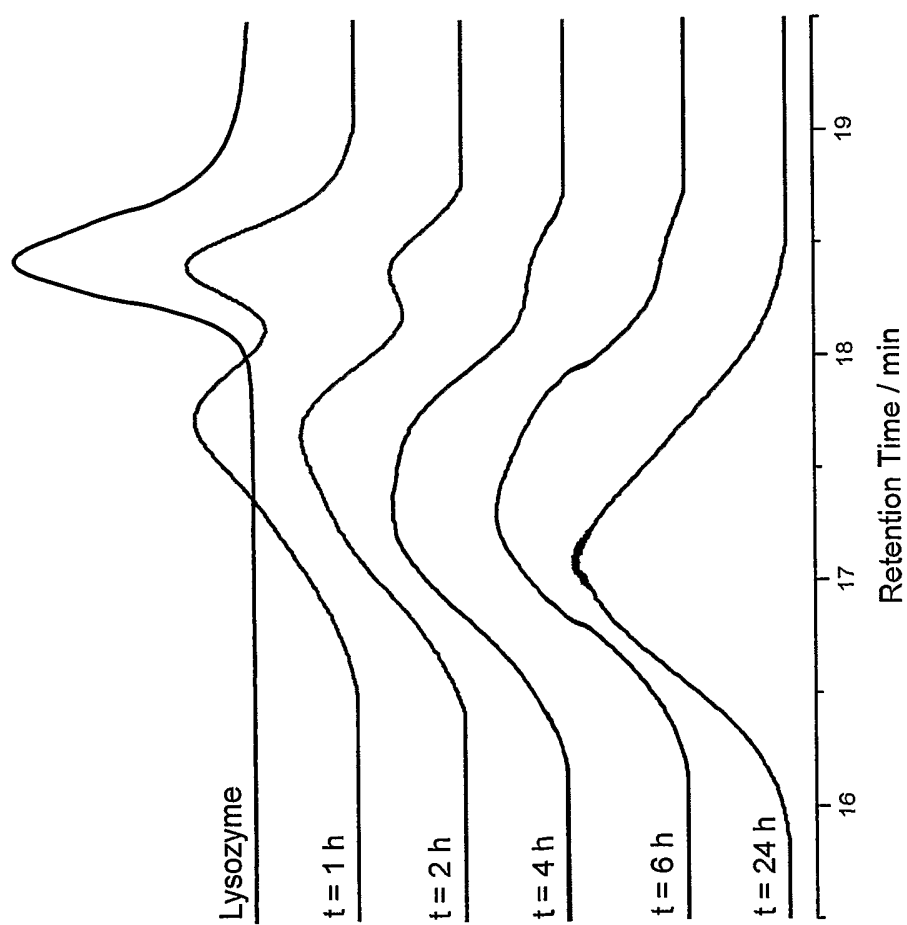


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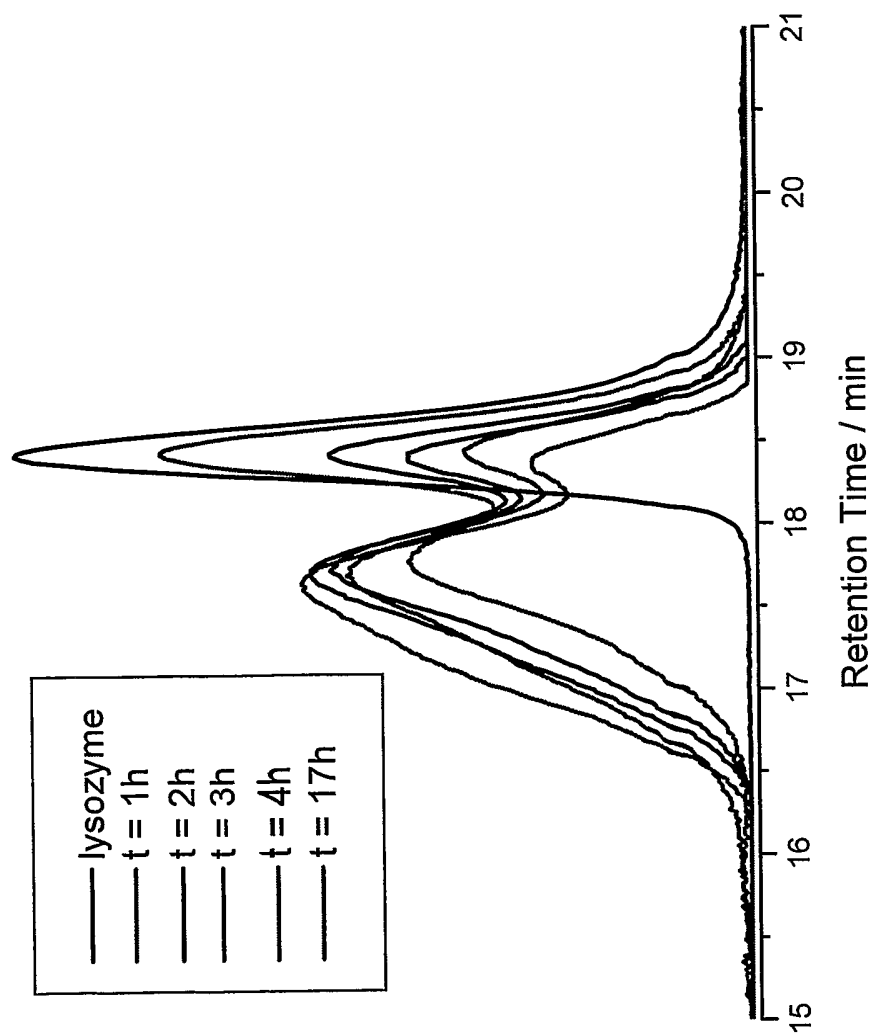


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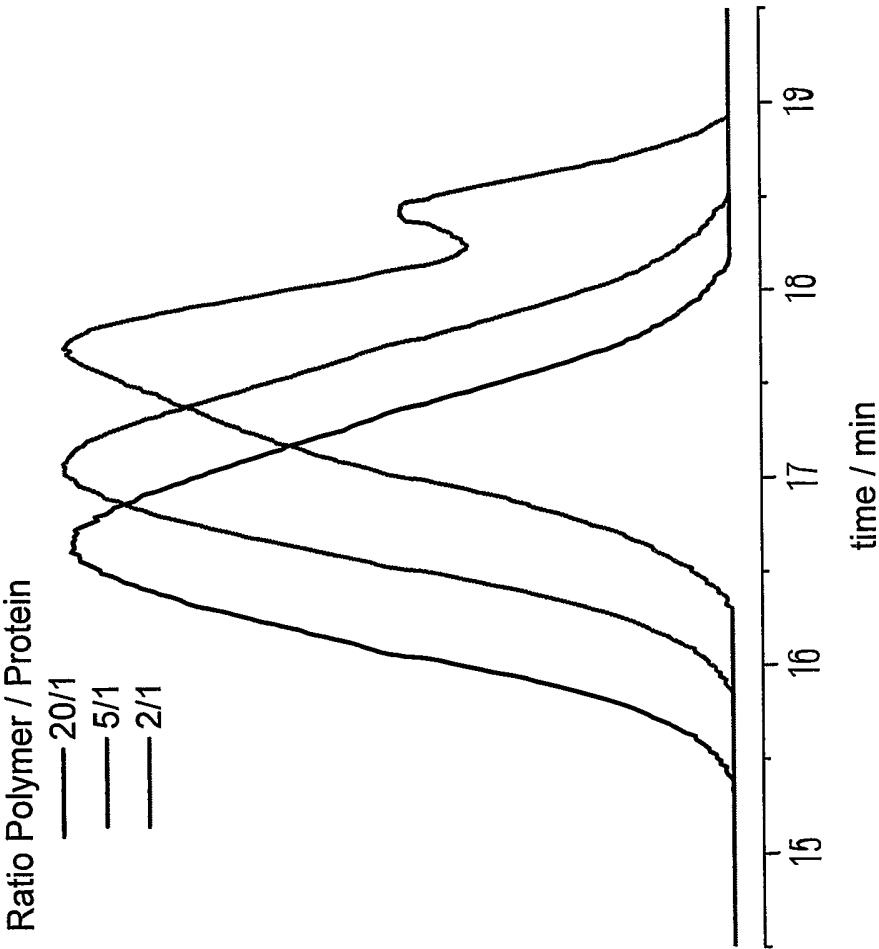


Figure 27.

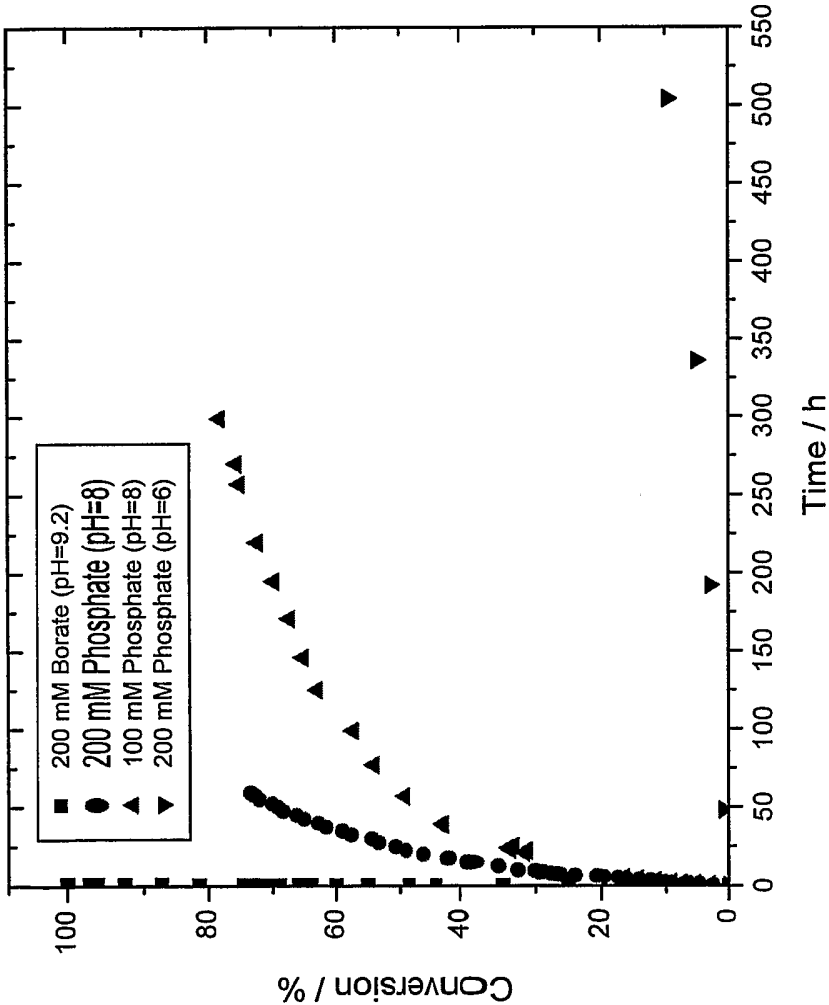


Figure 28.

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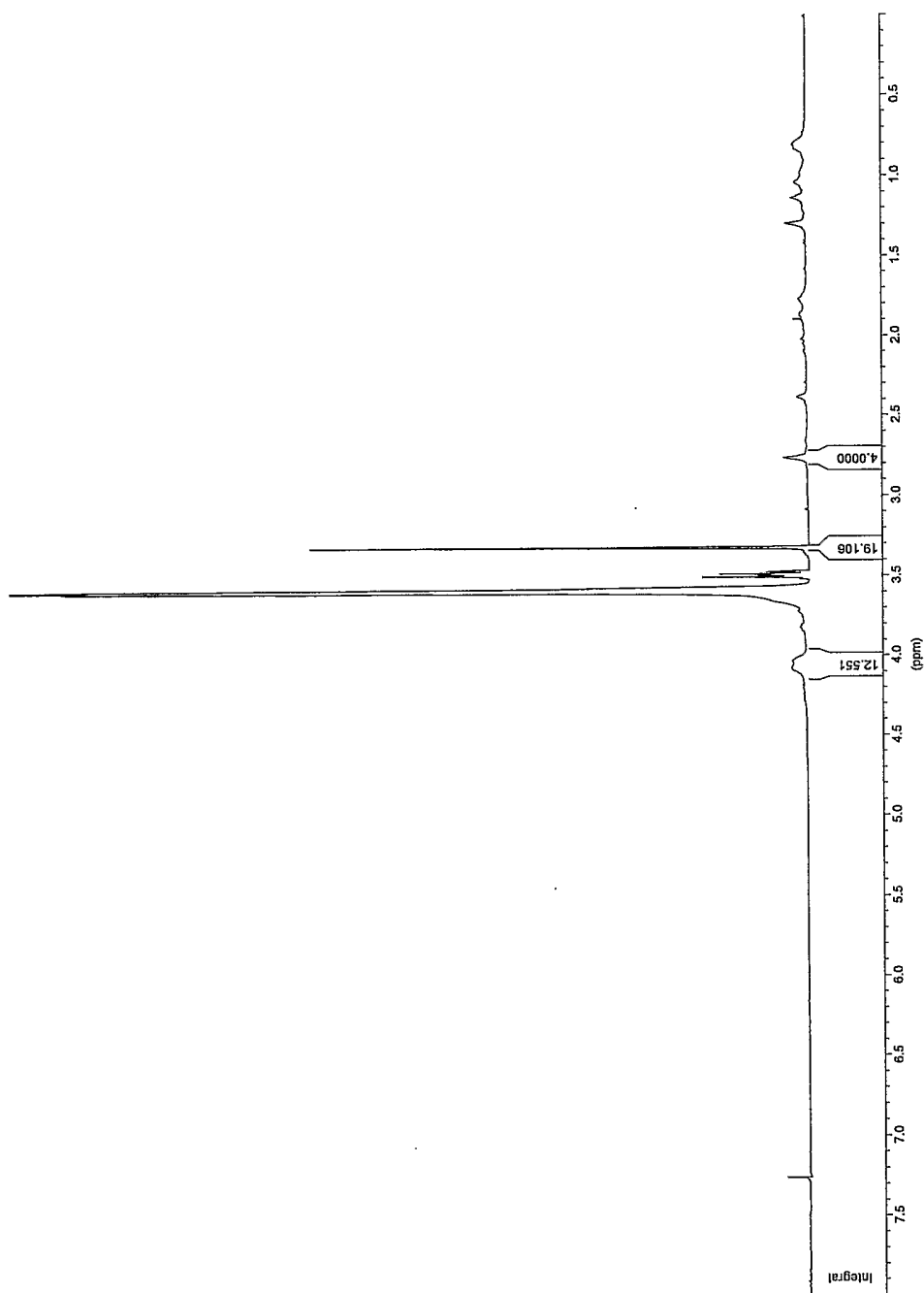


Figure 29.

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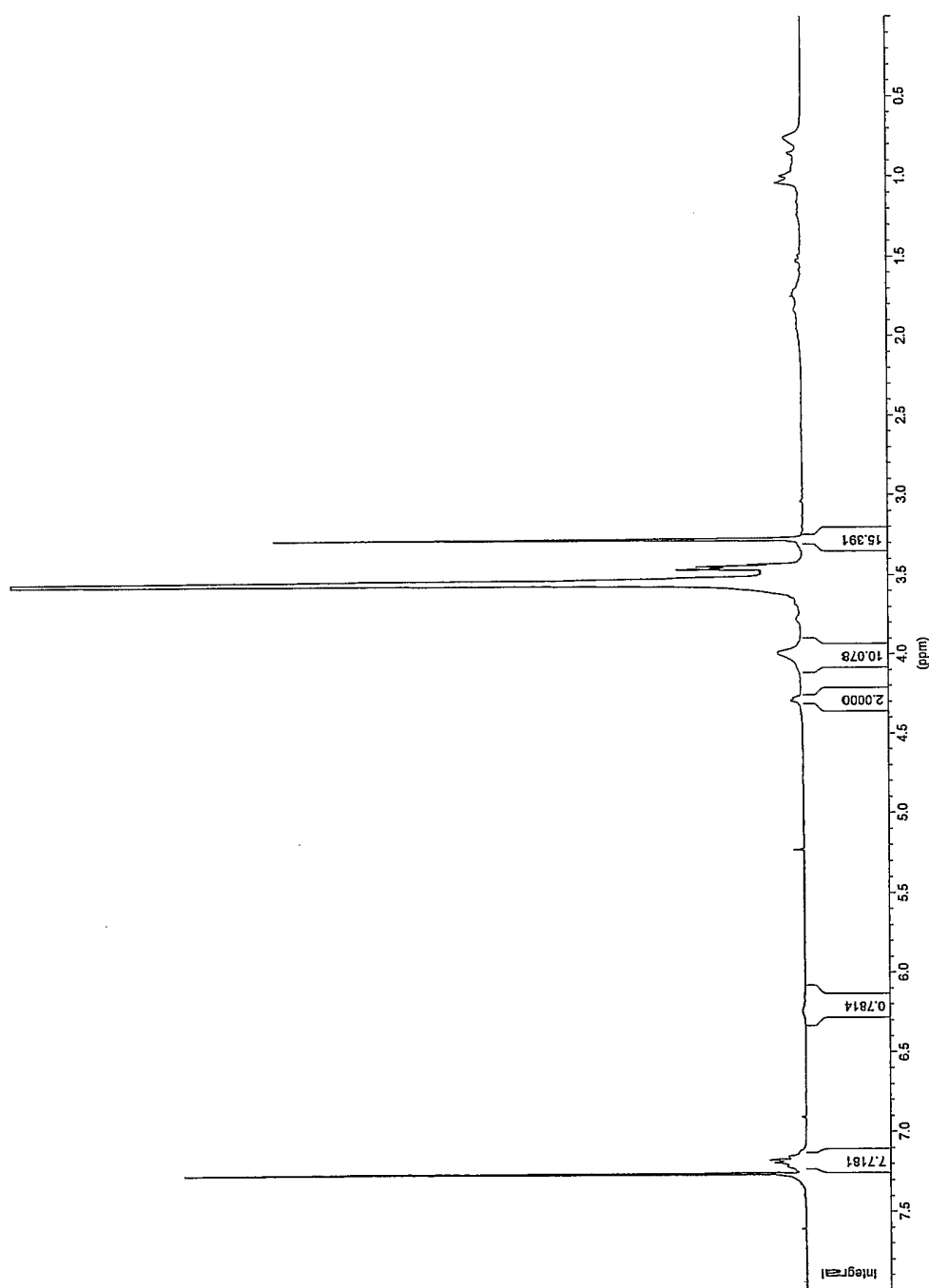


Figure 30.

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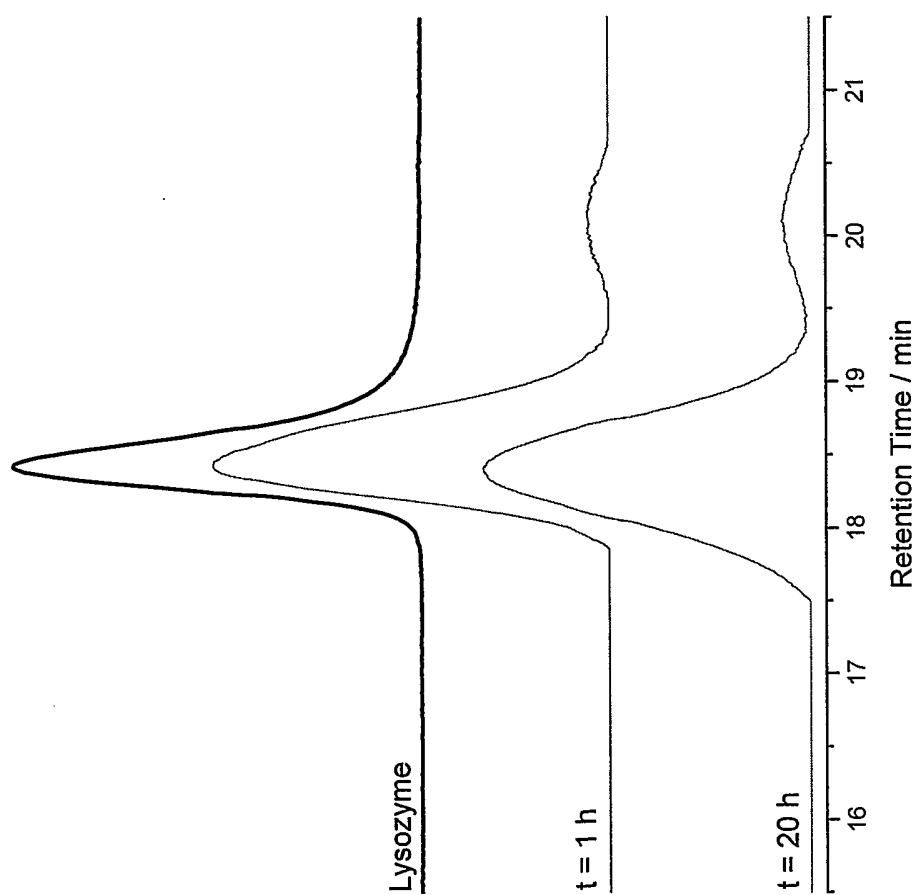


Figure 31.

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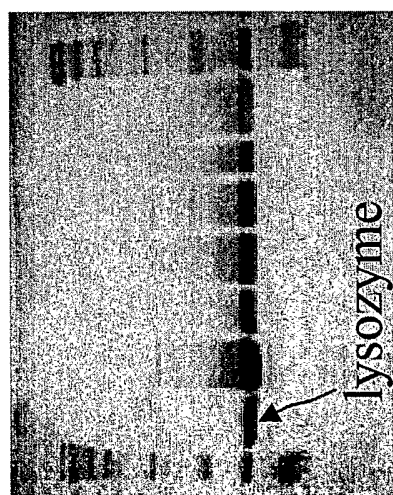
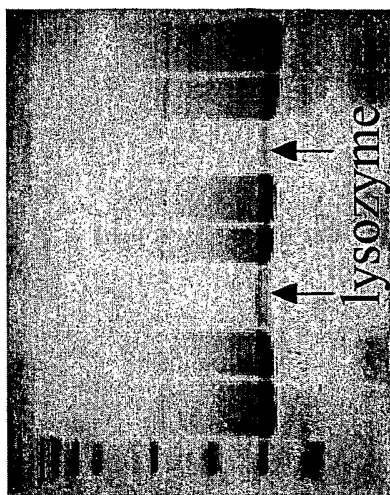


Figure 32

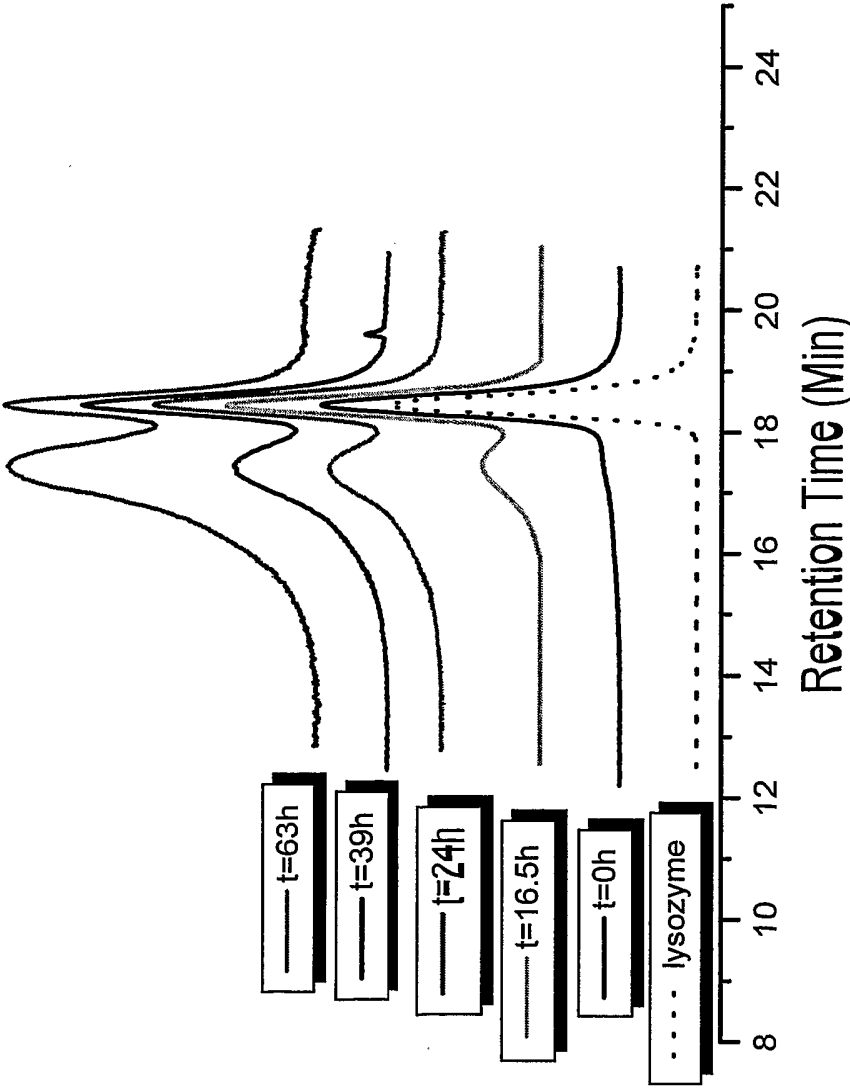


Figure 33.

Figure 34.

