United States Patent [19]
Rembaum

[54] POLYACROLEIN MICROSPHERES
[75] Inventor: Alan Rembaum, Pasadena, Calif.
[73] Assignee: California Institute of Technology, Pasadena, Calif.
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[52] U.S. Cl. ........................... 523/223; 204/159.21; 435/180; 526/315; 526/303.1; 252/301.36; 252/62.54; 424/82; 525/377; 525/380; 525/382
[58] Field of Search ........................ 526/315; 523/223; 435/180

References Cited
U.S. PATENT DOCUMENTS
3,105,801 10/1963 Bell et al. ... 204/154
3,819,555 6/1974 Kaufman ... 526/315
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4,191,838 3/1980 Merger et al. ... 526/315

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Primary Examiner—Wilbert J. Briggs, Sr.
Assistant Examiner—A. H. Koeckert
Attorney, Agent, or Firm—Marvin E. Jacobs

ABSTRACT
Microspheres of acrolein homopolymers and copolymer with hydrophilic comonomers such as methacrylic acid and/or hydroxyethylmethacrylate are prepared by cobalt gamma irradiation of dilute aqueous solutions of the monomers in presence of suspending agents, especially alkyl sulfates such as sodium dodecyl sulfate. Amine or hydroxyl modification is achieved by forming adducts with diamines or alkanol amines. Carboxyl modification is effected by oxidation with peroxides. Pharmaceuticals or other aldehyde reactive materials can be coupled to the microspheres. The microspheres directly form antibody adducts without agglomeration.

16 Claims, 4 Drawing Figures

ALDEHYDE MICROSPHERE
+NH₂OH

HYDROXY-AMINE
H₂N-(CH₂)n-OH
HYDROXYALKYLAMINE
NH₂-R-NR₂
DIAMINE
CH=N-R-NR₂
POLYAMINE
CH=NOH
POLYOXIMES
H₂O- C
POLYCARBOXYL

PHARMACEUTICAL-N=HC
MICROSHERE

PHARMACEUTICAL ADDUCT
ANTIBODY-N=HC
IMMUNO REAGENT

FLUOROCHROME-N=HC
FLUORESCENT MICROSPHERE

4,210,565 7/1980 Emmons .......................... 526/315
4,267,091 5/1981 George et al. .................... 526/315
Fig. 1.

Fig. 2.
**Fig. 3.**

**Fig. 4.**
POLYACROLEIN MICROSPHERES

ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 83-568 (72 Stat. 435; 42 USC 2457).

TECHNICAL FIELD

The present invention relates to the synthesis of polyacrolein microspheres, functional derivatives thereof, fluorescent and magnetic variations thereof, protein conjugates thereof and to the use of the conjugates in biological and chemical research and testing.

BACKGROUND OF THE PRIOR ART

The isolation and characterization of cell membranes and their components is essential for an understanding of the role in which surface membranes play in regulating a wide variety of biological and immunological activities. The present techniques used for this purpose are not quite satisfactory.

Knowledge of the nature, number and distribution of specific receptors on cell surfaces is of central importance for an understanding of the molecular basis underlying such biological phenomena as cell-cell recognition in development, cell communication and regulation by hormones and chemical transmitters, and differences in normal and tumor cell surfaces. In previous studies, the localization of antigens and carbohydrate residues on the surface of cells, notably red blood cells and lymphocytes, has been determined by bonding antibodies or lectins to such molecules as ferritin, hemocyanin or peroxidase which have served as markers for transmigration in presence of surfactant or by precipitation from solution containing surfactant. Magnetic, high density or electron dense microspheres can be prepared by coating metal particles or by suspension polymerization of glutaraldehyde in presence of a suspension of finely divided metal or metal oxide. It has been determined that the PGL microspheres exhibit some degree of non-specific binding to cells. Moreover, though some cross-linking occurs during the homopolymerization of glutaraldehyde, the polymer can be dissolved in highly polar solvents.

A process for polymerizing unsaturated aldehydes such as acrolein is disclosed in U.S. Pat. No. 3,105,801. The process comprises adding a small amount of acid or an acid-acting material to an aqueous solution containing acrolein or other unsaturated aldehyde and exposing the acidic medium to high energy ionizing radiation to form high molecular weight polymer in the form of light powders having non-uniform shapes and sizes. The polymers were not utilized as such but are dissolved in aqueous alkaline sulfur dioxide solution to form water soluble derivatives which are used as coatings or sizings for paper, cloth, fibers and the like. Bell et al also discusses the copolymerization of acrolein with a wide variety of ethynically unsaturated monomers such as ethylene diamine, pyridine or acrylic acids or esters, vinyl halides, etc. in amounts from 0.1 to 60%, preferably from 1% to 25% by weight of the monomer mixture. The monomer mixture can contain other agents such as stabilizing, suspending as emulsifying agents. Radia-
tion accelerators such as halides or metal salts may be added to the reaction mixture.

Though the polyacroleins prepared by Bell et al. have a high degree of available aldehyde function, there was no recognition of the use of such material as a biological reagent. Furthermore, the presence of extraneous ingredients interferes with the purity of the polymer and it would not be suitable as a biochemical protein bonding agent. Furthermore, specific modification of the material by copolymerization with certain comonomers designed to impart further properties such as non-specific binding and modification to add other functional groups for introduction of dyes, proteins or other materials would improve the flexibility of use of the material.

DESCRIPTION OF THE INVENTION

Novel acrolein interpolymer microspheres and functional, modified reaction products and protein adducts thereof, are produced in accordance with the invention. The size and properties of the microspheres can be controlled by selection of polymerization conditions and especially by selection of comonomers. The microspheres of the invention exhibit exceptional stability and can be derivatized by reaction with amines or with proteins without aggregation.

The non-aggregating microspheres are produced in accordance with this invention by the high-energy initiated interpolymerization of an unsaturated aldehyde such as acrolein and at least 20% by weight of at least one addition copolymerizable comonomer having a hydrophilic functional substituent selected from hydroxyl, amino or carboxyl.

Another manner of introducing functionality other than aldehyde onto the microspheres is by adduct reaction of the microspheres with compounds of the formula:

\[
N-R-Z
\]

where \( R^1 \) is hydrogen or a hydrocarbon group which may be aliphatic or aromatic preferably aryl such as phenyl or alkyl of 1 to 10 carbon atoms, \( R \) is a divalent hydrocarbon group such as alkylene of 1 to 20 carbon atoms and \( Z \) is a functional group such as amine or hydroxyl or \( RZ \) can be hydroxyl. Representative compounds are hydroxylamine or ethylene diamine. The microspheres can be modified to introduce carboxyl groups by oxidation with an agent such as hydrogen peroxide.

The microspheres of the invention exhibit little or no aggregation during or after derivatization reaction to introduce large amounts of antibodies or other proteins, fluorochromes, etc. The microspheres are insoluble, have functional groups directly reactive with protein, are easily dispersed and bind specifically to receptor sites and can be readily prepared in sizes from 100 Angstroms to 2,000 Angstroms, or up to 10 microns or larger if desired.

The derivatization procedure is simplified. The hydroxyl modified microspheres can be used to chelate metals as a purification media or as a support for a catalyst. The microspheres can be formed into a strong transparent film by drying on a surface or can be formulated to contain metals which can be utilized to form electron dense magnetic non-aggregating particles or magnetic coatings or films. The microspheres of the invention provide a reliable, simple method to label cells for research or analysis.

The microspheres of the invention can also be utilized as a substrate to bind pharmaceuticals containing functional groups reactive with aldehyde, the hydrophilic hydroxyl, carboxyl or amine substituent or the functional group \( Z \) of the adduct. The microsphere-pharmaceutical adduct is less likely to migrate and should reduce side effects. Furthermore, antibodies can be attached to the microsphere so that it migrates to specific cells having corresponding antigen receptor sites. Magnetic microspheres can be accumulated at a specific location in a subject by application of a magnetic field to that location.

These and many other features and attendant advantages of the invention will become apparent as the invention becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a series of graphs showing the effect of addition of comonomers on the size of acrolein copolymer microspheres.

FIG. 2 is a series of schematic reactions of polyacrolein microspheres and various modifying and ad-ducting reagents;

FIG. 3 is a pair of curves illustrating the aldehyde and carboxyl content of oxidized Acrolein-Methacrylic Acid copolymer microspheres and

FIG. 4 is a pair of curves demonstrating the kinetics of reaction of polyacrolein microspheres with an antibody.

DETAILED DESCRIPTION OF THE INVENTION

Initiation of copolymerization by high energy radiation in absence of chemical initiators or acid materials provides a purer and more evenly sized and shaped microsphere. The microspheres are produced by addition polymerization of a liquid polymerization system optionally including a dispersion of the metal particles in a monomer mixture containing a covalently bondable unsaturated monomer. More uniformly sized and shaped beads are formed in very dilute aqueous monomer mixtures of no more than 5% by weight, preferably 1 to 4% by weight of dissolved monomers. Surfactants may be present to aid in the dispersion of the metal particles and in suspending the microspheres.

The polymerization proceeds with or without stirring with application of high energy radiation capable of generating free radicals in the aqueous system. The radiation source is suitably a cobalt 60 gamma source or cesium source and doses of 0.05 to 2.0 megarads are sufficient for polymerization. It is believed that polymer chains grow from the surface of metallic particles. The reaction is preferably conducted under oxygen excluding condition, generally by applying vacuum to the reaction vessel or by displacing oxygen gas from the system with an inert gas such as nitrogen. After polymerization has proceeded to completion, the reaction mixture is made neutral by adding acid or base, passed through mixed ion exchange resins to remove emulsifiers or any free metal particles. Further purification is achieved by centrifugation on a sucrose gradient.
The stabilizing agent is suitably an aqueous soluble agent to the aqueous polymerization system before polymerization is found to further reduce agglomeration. The stabilizing agent is sometimes sparingly water soluble. Hydrophobic characteristics can also be provided with monomers such as lower alkyl acrylates suitably methyl methacrylate or ethyl methacrylate or a vinyl pyridine. Vinyl pyridines suitable for use in the invention are 2-vinyl pyridine, 4-vinyl pyridine and 2-methyl-5-vinyl pyridine.

Small microspheres (of the order of 100 to 500 Angstroms in diameter) are formed in solutions containing small amounts, typically from 10 to 150 millimoles, of an alkali metal C_6 to C_20 alkyl sulfate surfactant such as sodium lauryl sulfate (SLS) or sodium dodecyl sulfate (SDS).

The ethylenically unsaturated aldehydes should comprise at least 10% by weight of the monomer mixture preferably from 20% to 90% by weight thereof. The aldehydes preferably have the ethylenic group in an aliphatic position relative to the aldehyde group and can be selected from those aldehydes containing up to 20 carbon atoms such as acrolein, methacrolein, alpha-ethyl acrolein, alpha-butyraldehyde, alpha-chloroacrolein, beta-phenylacrolein, alpha-cyclohexyl acrolein and alpha-decylacrolein. Preferred aldehydes contain 4 to 10 carbon atoms and especially acrolein and C_5 to C_9 alkyl and cycloalkyl substituted derivatives thereof.

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The mono-unsaturated covalent-bonding monomers are freely water soluble and should comprise from 10 to 50% of the monomer mixture. These monomers are suitably selected from amino, carboxyl or hydroxyl substituted acrylon monomers. Exemplary monomers are acrylamide (AM), methacrylamide (MAM), acrylic acid, methacrylic acid (MA), dimethylaminomethacrylate or hydroxyl-lower alkyl or amino-lower-alkyl-acrylates such as those of the formula:

\[
\begin{align*}
\text{CH}_2 \text{O} \\
\text{R}^1 \quad \text{C} \quad \text{R}^2 \quad \text{Z}
\end{align*}
\]

where R^1 is hydrogen or lower alkyl of 1-8 carbon atoms, R^2 is alkylene of 1-12 carbon atoms, and Z is —OH or R^3—N—R^4 where R^3 or R^4 are individually selected from H, lower alkyl or lower alkoxy of 1-8 carbon atoms. 2-hydroxyethyl methacrylate (HEMA), 3-hydroxypropyl methacrylate and 2-aminoethyl methacrylate are readily available commercially. Porosity and hydrophilicity increase with increasing concentration of monomer.

Inclusion of polysaturated compounds provides cross-linked beads. The polysaturated compounds are generally present in the monomer mixture in an amount from 0.1-20% by weight, generally 6-12% by weight and are suitably a compatible diene or triene polyvinyl compound capable of addition polymerization with the covalent bonding monomer such as ethylene glycol dimethacrylate, trimethylol-propane-trimethacrylate, N,N'-methylene-bis-acrylamide (BAM), hexahydro-1,3,5-triacycroyl-striazine or divinyl benzene.

For small particle size and additional reduction in non-specific binding and agglomeration the monomer mixture preferably contains a monomer capable of imparting negative charge such as methacrylic acid (MA).

The addition of 0.05 to 5%, by weight, of a stabilizing agent to the aqueous polymerization system before polymerization is found to reduce agglomeration. The stabilizing agent is suitably an aqueous soluble polymer such as a polyalkylene oxide polymer or non-ionic surfactants such as Tween which are polyoxyethylene derivatives of fatty acid partial esters of sorbitol, Triton X, or dextan. The polylithers generally have a molecular weight from 10,000 to 10,000,000, preferably 400,000 to 6,000,000 and are polymers of ethylene oxide, propylene oxide or their mixtures. Polyeithylene oxides (PEO) and Triton X are preferred.

The smaller microspheres (50 to 200 Angstroms in diameter) are formed in solutions containing small amounts, typically from 10 to 150 millimoles, of an alkali metal C_6 to C_20 alkyl sulfate surfactant such as sodium lauryl sulfate (SLS) or sodium dodecyl sulfate (SDS).

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The mono-unsaturated covalent-bonding monomers are freely water soluble and should comprise from 10 to 50% of the monomer mixture. These monomers are suitably selected from amino, carboxyl or hydroxyl substituted acrylon monomers. Exemplary monomers are acrylamide (AM), methacrylamide (MAM), acrylic acid, methacrylic acid (MA), dimethylaminomethacrylate or hydroxyl-lower alkyl or amino-lower-alkyl-acrylates such as those of the formula:

\[
\begin{align*}
\text{CH}_2 \text{O} \\
\text{R}^1 \quad \text{C} \quad \text{R}^2 \quad \text{Z}
\end{align*}
\]

where R^1 is hydrogen or lower alkyl of 1-8 carbon atoms, R^2 is alkylene of 1-12 carbon atoms, and Z is —OH or R^3—N—R^4 where R^3 or R^4 are individually selected from H, lower alkyl or lower alkoxy of 1-8 carbon atoms. 2-hydroxyethyl methacrylate (HEMA), 3-hydroxypropyl methacrylate and 2-aminoethyl methacrylate are readily available commercially. Porosity and hydrophilicity increase with increasing concentration of monomer.

Inclusion of polysaturated compounds provides cross-linked beads. The polysaturated compounds are generally present in the monomer mixture in an amount from 0.1-20% by weight, generally 6-12% by weight and are suitably a compatible diene or triene polyvinyl compound capable of addition polymerization with the covalent bonding monomer such as ethyleneglycol dimethacrylate, trimethylol-propane-trimethacrylate, N,N'-methylene-bis-acrylamide (BAM), hexahydro-1,3,5-triacycroyl-striazine or divinyl benzene.

For small particle size and additional reduction in non-specific binding and agglomeration the monomer mixture preferably contains a monomer capable of imparting negative charge such as methacrylic acid (MA).

The mixture may contain 0-40% suitably 10 to 30% of sparingly water soluble monomers having hydrophobic characteristics since this is found to result in freely-suspended, individual, small beads. The cross-linking agent is sometimes sparingly water soluble. Hydrophobic characteristics can also be provided with monomers such as lower alkyl acrylates suitably methyl methacrylate or ethyl methacrylate or a vinyl pyridine. Vinyl pyridines suitable for use in the invention are 2-vinyl pyridine, 4-vinyl pyridine and 2-methyl-5-vinyl pyridine.

Small microspheres (of the order of 100 to 500 Angstroms) containing electron-dense metals provide higher spatial resolution of cell surface features. Immunomicrospheres containing electron-dense metals provide more stable labels than gold particles with physically absorbed antibodies that are presently used for cell labeling. The metal containing microspheres can be synthesized by, in situ, polymerization of the microspheres in presence of a suspension of finely-divided metal particles or compounds of the metal, preferably a colloidal dispersion of the metal. The metal is incorporated into the microsphere in an effective amount of from 0.5% to 40% by weight, generally from 5% to 25% by weight.

The metal or metal compound particles are preferably fine, evenly sized materials having a uniform diameter smaller than the resultant microsphere diameter, typically below 1000 Å, generally from 25 Å to 500 Å.

The metals are preferably the electron-dense heavy metals having a high atomic number above 50, preferably above 75 such as Pb, Ni, Co, Pt, Au, Fe. The metal may be magnetically attractive such as Fe, Ni, Co or alloys thereof or an inorganic magnetic compound such as a metal oxide. The magnetic material is preferably a magnetic iron oxide of the formula Fe_3O_4. Some hard, ceramic type ferrites, such as lithium ferrites can also be used. The metal or compound can be made into a readily dispersible form by suspension in water containing a surfactant such as polyethylene imine.

Post polymerization reaction with specific fluorochrome reagents that are not in themselves fluorescent, results in a fluorescent microsphere by forming fluorescent chromophores attached to the polymer. Anthrone reacts with acrolein units to form a benzanthrone fluorogen and m-aminophenol reacts with the acrolein structure to form the fluorogen, 7-hydroxynaphthoquinone. Aminofluorescein also reacts with aldehyde groups to form fluorescent microspheres.

The microspheres can also be rendered fluorescent during polymerization in presence of fluorochrome compounds containing aldehyde or hydroxyl reactive groups such as aminofluorescein, 9-amino acridine, propidium bromide or fluorescein isothiocyanate (FITC). Highly fluorescent microspheres can also be prepared by suspension polymerization in presence of fluorochromes containing unsaturated groups capable of reaction with acrolein. Examples of practice follow:

Reagents: Methacrylic acid (MA), 2-hydroxyethyl methacrylate (HEMA), acrolein, ethylene diamine were fractionally distilled. Polyethylene oxide (PEO, M_w 100,000) N,N'-methylene-bis-acrylamide (BAM), hydroxyline hydrochloride, 1,6-hexane diamine, 1-Lysine, 1-ethyl-3-(3-dimethyl amino propyl) carbodiimide were used as received.

Synthesis: Acrolein or monomer mixtures consisting of HEMA and acrolein or HEMA, BAM, MA and...
acrolein formed homogeneous solutions in distilled water containing 0.4% PEO or 64 mM of SDS. After deamination with nitrogen the mixtures were irradiated in CO gamma source at room temperature (dose rate 0.12 Mr/hour) for 4 hours. The reaction product was purified by three centrifugations and kept in distilled water.

Methods: The aldehyde content was determined from the percent nitrogen of the oxime prepared by the reaction of an aqueous suspension with hydroxylamine hydrochloride [P. J. Bochert Kunstoffe 51 (3) 137 (1961)].

<table>
<thead>
<tr>
<th>% (v/v) Acrolein</th>
<th>Mole % Acrolein</th>
<th>% Yield</th>
<th>Microspheres/mg</th>
<th>% Nitrogen Found</th>
<th>Number of Aldehyde Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>44</td>
<td>61.1</td>
<td>0.84 x 10^-10</td>
<td>3.06</td>
<td>1.4 x 10^-18</td>
</tr>
<tr>
<td>40</td>
<td>55</td>
<td>50.0</td>
<td>3.1</td>
<td>4.02</td>
<td>1.8 x 10^-18</td>
</tr>
<tr>
<td>50</td>
<td>65</td>
<td>47.9</td>
<td>3.7</td>
<td>4.84</td>
<td>2.2 x 10^-18</td>
</tr>
<tr>
<td>60</td>
<td>74</td>
<td>37.8</td>
<td>4.6</td>
<td>5.59</td>
<td>2.5 x 10^-18</td>
</tr>
<tr>
<td>70</td>
<td>82</td>
<td>36.3</td>
<td>6.5</td>
<td>6.57</td>
<td>3.0 x 10^-18</td>
</tr>
<tr>
<td>80</td>
<td>88</td>
<td>21.6</td>
<td>5.2</td>
<td>8.58</td>
<td>4.0 x 10^-18</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td>17.6</td>
<td>6.4</td>
<td>13.06</td>
<td>6.4 x 10^-18</td>
</tr>
</tbody>
</table>

aMole % of acrolein in monomer mixture.
bCalculated using spherical microspheres of diameter shown in FIG. 1 and a density of 1.2 g/ml.
cTheoretical nitrogen for homopolymer is 19.72%.

It was found that at high pH 10 the number of free amino groups was comparable to the number of aldehyde groups found by hydroxylamine analysis. This reaction allows the efficient conversion of aldehyde functions to amine functions, removed from the surface of the spheres by a two to six carbon spacer arm.

The monomer mixture utilized in the experiment in Table 2 was modified by maintaining the ratio of HEMA, MA and BAM constant while adding increasing amounts of acrolein. As shown in Table 3 which follows, the aldehyde content increased with increasing phobicity.

When the acrolein homopolymer microsphere suspension was evaporated to dryness, a brittle film was formed. However, evaporation of the HEMA—copolymer (35 mol percent HEMA) microsphere suspension to dryness resulted in a strong, flexible film.

EXAMPLE 3

Seven of the copolymers were reacted with hydroxylamine chloride to form hydroxyl functional microspheres. The aldehyde content was analyzed by this procedure as shown in Table 1.
acrolein content proving that acrolein was being incorporated into the copolymer.

<table>
<thead>
<tr>
<th>MOLE % ACROLEIN</th>
<th>% N</th>
<th>NO. ALDEHYDE GROUPS/mg x 10^{-18}</th>
</tr>
</thead>
<tbody>
<tr>
<td>35.9</td>
<td>2.26</td>
<td>1.35</td>
</tr>
<tr>
<td>58.5</td>
<td>4.32</td>
<td>1.93</td>
</tr>
<tr>
<td>75.8</td>
<td>6.57</td>
<td>2.90</td>
</tr>
<tr>
<td>95.3</td>
<td>12.16</td>
<td>5.83</td>
</tr>
</tbody>
</table>

**EXAMPLE 7**

The copolymer of Example 6 was reacted with an adduct of fluorescein isothiocyanate (FITC) and 1,6-diamino-hexane which resulted in microspheres of high fluorescent intensity.

**EXAMPLE 8**

An allyl amine adduct of FITC was prepared. Addition of 0.1% by weight of the adduct to the polymerization system of Example 6 resulted in an addition interpolymerized fluorescent copolymer microsphere.

**EXAMPLE 9**

An adduct of 1,6-diaminohexane (DAH) and FITC was prepared. Addition of 0.1% of the adduct to the polymerization system of Example 6 resulted in introduction of fluorescent chromophore by condensation with aldehyde groups to the addition polymerized copolymer.

**EXAMPLE 10**

Dispersible iron oxide was prepared by dissolving 10 g of ferrous chloride and 13.5 g of ferric chloride in 210 cc of 1% w/v polyethylene imine M.W. 1800 aqueous solution. 50% NaOH was added to pH 7. The reaction mixture was refluxed for 3 hours, dialyzed extensively against water and separated magnetically three times from nonmagnetic particles. The magnetic polyethylene imine-iron oxide particles were redispersed in water (30%) to 14.5 ml of an acrolein microsphere suspension taken at 0.30, 60, 120 and 180 minutes. Aliquot were immediately added to 400 ml of a 1% (w/v) solution of egg albumin in PBS and centrifuged at 15,000 x g for 4 min., resuspended and washed once in PBS as above. The acrolein microspheres exhibited direct binding of about 7-9% by weight of antibody whereas a control HEMA-BAM microsphere was able to bind less than 1% by weight of the microsphere.

**EXAMPLE 11**

The monomer mixture was added to a water suspension of acrolein microspheres (total 15 mg) and 0.5 mg of 2 mg 1 ml solution of 125 Iodine labeled goat immunoglobulin G (spec. activity 1 x 10^6 cpm/mg) in PBS. The mixture was rotated for 3 hrs. and 400 microliters aliquots were taken at 0, 30, 60, 120 and 180 minutes. Aliquot were immediately added to 400 ml of a 1% (w/v) solution of egg albumin in PBS and centrifuged at 15,000 x g for 4 min., resuspended and washed once in PBS as above.

**EXAMPLE 12**

Dispersible iron oxide was prepared by dissolving 10 g of ferrous chloride and 13.5 g of ferric chloride in 210 cc of 1% w/v polyethylene imine M.W. 1800 aqueous solution. 50% NaOH was added to pH 7. The reaction mixture was refluxed for 3 hours, dialyzed extensively against water and separated magnetically three times from nonmagnetic particles. The magnetic polyethylene imine-iron oxide particles were redispersed in water and then sonicated with a clinical sonicator for 10 minutes. Magnetic particles having a diameter of 300 Angstroms with amine groups on the surface were formed. When 1% of the polyethylene imine-iron oxide is added to the solution of monomers of Example 6 and subjected to gamma irradiation microspheres containing a dispersion of magnetic iron particles is produced.

**EXAMPLE 13**

Binding of Methotrexate to Polyacrolein Microspheres

I. Preparation of Microspheres

<table>
<thead>
<tr>
<th>[10%]</th>
<th>Total monomer concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>90% Acrolein</td>
<td></td>
</tr>
<tr>
<td>10% Methacrylic Acid</td>
<td></td>
</tr>
<tr>
<td>in 25 ml 0.4% PEO 100,000 MW pH 2.8</td>
<td></td>
</tr>
<tr>
<td>Degas with Nitrogen</td>
<td></td>
</tr>
<tr>
<td>Co Gamma Radiation 5h: Dose—0.12 Mic/hr.</td>
<td></td>
</tr>
<tr>
<td>Wash 3X</td>
<td></td>
</tr>
<tr>
<td>Resuspend 36 ml H_2O</td>
<td></td>
</tr>
<tr>
<td>Conc: 27.5 mg/ml</td>
<td></td>
</tr>
<tr>
<td>Yield: 46.13%</td>
<td></td>
</tr>
</tbody>
</table>

II. Reaction of Microspheres with Carbodiimide

| 50 mg of microspheres |
| 0.6 ml DAH (80% aqueous solution) |
| Repeat 4 hr. with shaking at room temperature |
| Wash 3X |
| Resuspend in 10 ml H_2O |
| III. Reaction of Microspheres with Carbodiimide |
| Add 20 mg of carbodiimide to 50 mg of DAH microspheres |
| Sonicate 10 minutes |
| Adjust pH to 6 with NaH_2PO_4 |
| Add 10 mg methotrexate in 2 ml H_2O |
| Check to be sure pH is still 6.0 |
| Sonicate 2 minutes |
| Shake overnight at room temperature |
| Spin down 3X |
| Take spectrum of first supernate. Spectrum indicates that more than 90% of methotrexate adducted with the microspheres.
A new convenient immunoreagent in form of acrolein copolymer microspheres was synthesized in a variety of sizes and with a relatively narrow size distribution. High intensity of fluorescence can be imparted to aldehyde functional groups by covalent bonding with antibodies, enzymes and other proteins in a single step. Therefore this immunoreagent eliminates the previously used intermediate steps in which the cyanogen bromide and carbodiimide reaction was used. The high specificity of the microspheres, at least as far as human rbc is concerned is also a desirable property. A minor synthetic modification yields fluorescent, magnetic microspheres for a large number of potential applications. The polyacrolein copolymer microspheres of this invention contain approximately twice as many aldehyde groups as the comparable glutaraldehyde copolymer microspheres.

The use of magnetic particles has created a great deal of interest in biochemical research and clinical medicine when used as supports for immobilized enzymes. Their easy retrieval from liquids containing colloids and undissolved solids should be of practical value. The separation of proteins and chemical compounds by affinity chromatography can be simplified by elimination of tedious centrifugation procedures and column chromatography steps. Magnetic particles have also recently been tested in radioimmunossay techniques in hyperthermia treatment of cancer, in guidance of magnetic particles to a vascular malformation such as cerebral aneurism with the intent to seal the defect by inducing thrombosis. Other proposed applications have been as tracers of blood flow or vehicles for drug delivery. The first successful application of magnetic immunomicrospheres to the separation of B and T cells has been demonstrated. There is little doubt that physical sorting of cell subpopulations has become a necessity. Many separation methods, while useful are limited by the restricted set of parameters upon which separation can be based and by the fact that they are batch techniques. New flow cytometers and sorters permit quantitative multiparameter measurements and sorting based on these measurements, but are limited as far as the number of cells that can be separated in a given time. Magnetic cell sorters have the potential of cell separation in a continuous process. Evidence obtained using model cell systems indicates that magnetic immunomicrospheres of desirable sizes can be conjugated with proteins in a simple and convenient manner, therefore offer a potential for large scale immunological cell sorting as well as other applications.

It is to be understood that only preferred embodiments of the invention have been described and that numerous substitutions, modifications and alterations are permissible without departing from the spirit and scope of the invention as defined in the following claims.

I claim:

1. A composition comprising an aqueous suspension of small, polymeric microspheres having a diameter from 500 Angstroms to 10 microns comprising the addition interpolymerize of a monomer mixture consisting essentially of:

20% to 90% by weight of an unsaturated aldehyde selected from acrolein and C1 to C9 aryI, alkyl or cycloalkyl derivatives thereof;

10% to 50% by weight of at least one addition copolymerizable mono-unsaturated, freely water-soluble acrylonitrile copolymer substituted with a hydrophilic substituent selected from amino, carboxyl or hydroxy; and

0.1 to 20% by weight of an addition copolymerizable, polysaturated cross-linking agent.

2. A composition according to claim 1 in which the diameter of the microspheres is from 100 Angstroms to 2000 Angstroms.

3. A composition according to claim 1 in which the aldehyde is selected from acrolein, methacrolein, alpha-ethyl acrolein, alpha-buty lacrolein, alpha-chloroacrolein, beta-phenylacrolein, alpha-cyclohexylacrolein and alpha-decylacrolein.

4. A composition according to claim 1 in which the aldehyde is acrolein.

5. A composition according to claim 1 in which the comonomer is selected from acrylamide, methacrylamide, acrylic acid, methacrylic acid, dimethylaminomethacrylate or compounds of the formula:

$$\begin{align*}
\text{CH}_2\text{O} & \\
\text{R}_1\text{C} & \text{-C}-\text{R}_2\text{-Z}
\end{align*}$$

where R1 is hydrogen or lower alkyl of 1-8 carbon atoms, R2 is alkylene of 1-12 carbon atoms and Z is -OH or

$$\begin{align*}
\text{R}_3\text{-N} & \text{-R}_4
\end{align*}$$

where R3 or R4 are individually selected from H, lower alkyl or lower alkoxy of 1-8 carbon atoms.

6. A composition according to claim 5 in which the comonomer comprises hydroxyethyl methacrylate.

7. A composition according to claim 5 in which the comonomer imparts a negative charge to the microsphere.

8. A composition according to claim 5 in which said comonomer is methacrylic acid.

9. A composition according to claim 1 in which the cross-linking agent is present in an amount from 6 to 2% by weight and is selected from a polyvinyl diene or triene capable of addition polymerization with the covalent bonding monomer.

10. A composition according to claim 1 in which the cross-linking agent is bis-acrylamide.

11. A composition according to claim 1 in which the monomer mixture further includes 10% to 30% by weight of sparingly water soluble monomers selected from lower alkyl acrylates or vinyl pyridines.

12. A composition according to claim 1 further including 0.05 to 5% by weight of a copolymerizable fluorescent chromophore monomer.

13. A composition according to claim 12 in which the fluorescent monomer contains functional groups reactive with aldehyde.

14. A composition according to claim 13 in which the fluorescent monomer contains addition polymerizable unsaturated groups.

15. A composition according to claim 1 in which said microspheres contain a dispersion of metal particles.

16. A composition according to claim 15 in which the metals are magnetizable.
UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 4,413,070
DATED : November 1, 1983
INVENTOR(S) : Alan Rembaum

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

ABSTRACT, line 2, correct "hydrophilic"

Column 6, lines 42-43, correct "fluorochrome"

Column 7, line 19, correct "deaeration"

Column 7, line 27, correct "Fourier"

Column 9, line 27, correct "polymerization"

Column 9, line 36, insert --(-- before M.W.

Column 11, line 4, correct "fluorescent"

Column 12, line 44, change "2%" to --12%--

Signed and Sealed this
Twenty-fifth Day of September 1984

[SEAL]

Attest:

GERALD J. MOSSINGHOFF
Attesting Officer
Commissioner of Patents and Trademarks