Biocompatible polymeric microspheres having an average diameter below about 3 microns and having a density at least 15% greater or lesser than organic cells and having covalent binding sites are provided in accordance with this invention. The microspheres are obtained by copolymerizing a hydroxy or amine substituted acrylic monomer such as hydroxyethylmethacrylate with a light or dense comonomer such as a fluoromonomer. A lectin or antibody is bound to the hydroxy or amine site of the bead to provide cell specificity. When added to a cell suspension the marked bead will specifically label the cell membrane by binding to specific receptor sites thereon. The labelled membrane can then be separated by density gradient centrifugation.

13 Claims, No Drawings
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). This is a division of application Ser. No. 634,292 filed Nov. 24, 1975. This is a division of application Ser. No. 634,929 filed Nov. 24, 1975.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to uniformly sized polymeric microspheres, to methods of making the microspheres and to their use in labelling cell surfaces.

2. Description 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 unsatisfactory.

Most biological studies depend on the knowledge of cell membrane structure and its surface properties because cell functions are controlled by surface interactions between cell membranes and their environment. Thus the cell membrane properties determine the uptake of nutrients, growth, adhesion to other cells or artificial surfaces, removal of foreign particles (phagocytosis) etc. Of particular interest are the cell membrane receptors of normal and transformed cells and the interaction of specific sites on the membrane with chemotherapeutic or cytotoxic agents. Information on this interaction is necessary for practical applications, e.g. development of diagnostic tests or destruction of diseased cells. The separation of cell membranes and the isolation of cell receptors is the first step in the study of their properties or their interaction with natural or foreign elements. Although several methods of membrane separation are at present used and new methods are being investigated, none of them is satisfactory and a good technique for isolation of specific sites on the membrane surface is non-existent.

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 macromolecules as ferritin, hemocyanin or peroxidase which have served as markers for transmission electron microscopy. With advances in high resolution scanning electron microscopy (SEM), however, the topographical distribution of molecular receptors on the surfaces of cell and tissue specimens can be readily determined by similar histochemical techniques using newly developed markers resolvable by SEM.

Recently commercially available polystyrene latex particles have been utilized as immunologic markers for use in the SEM technique. The surface of such polystyrene particles is hydrophobic and hence certain types of macromolecules such as antibodies are adsorbed on the surface under carefully controlled conditions. However, such particles stick non-specifically to many surfaces and molecules and this seriously limits their broad application. Though these particles, while of the proper density for separating adsorbed or labelled membranes from other membranes are unchanged and are not capable of any derivitization by ionic or covalent bonding of protein and other biological molecules, and are thus limited in use to generalized studies on phagocytosis.

The preparation of small, stable, spherical particles which are biocompatible, i.e., do not interact nonspecifically with cells or other biological components and which contain functional groups to which specific proteins and other bio-chemical molecules can be covalently bonded is disclosed in copending application Ser. No. 434,124, filed Jan. 17, 1974, now U.S. Pat. No. 3,957,741 issued May 18, 1976.

The hydroxyl or amino groups can be activated by cyanogen bromide for covalent bonding of proteins and other chemicals containing amino groups to the polymeric latex. Methacrylic acid residues which impart a negative charge onto the particles are likely to prevent non-specific binding to cell surfaces and to provide carboxyl groups to which a variety of bio-chemical molecules can be covalently bonded using the carbodiimide method. Cross-linking of the polymeric matrix is essential to maintain the stability and size of the particles in both aqueous solution and in organic solvents commonly used in the fixation and dehydration of biological specimens for electron or light microscopy.

The polymeric microspheres ranging in diameter from 300 to 2000Å have been successfully utilized as biocompatible immunochemical markers of red blood cells and lymphocytes in scanning electric and light microscopy. However, the density of the microspheres is so close to that of the cell membranes that isolation of the cell membranes or bound receptor sites is not possible.

SUMMARY OF THE INVENTION

Amine-, hydroxyl- and/or carboxyl-substituted microspheres are provided in accordance with the invention having a density of at least 1.30 g/cc, preferably above 1.40 g/cc, or a density below 1.15 g/cc preferably below 1.05 g/cc. The density of cellular organelles is of the order of about 1.20 g/cc. The beads of the invention being considerably smaller than biological cells and being capable of binding a protein conjugate can attach to specific receptor sites on the surface of the cell membrane and after fragmentation of the membrane can be recovered by sedimentation or centrifugation techniques.

The microspheres will find use in lectin, antibody or sugar derivatized forms. They can be used to isolate membrane fragments enriched for the appropriate cellular ligand(s) which bind to the substance covalently attached to the bead. The microspheres currently available permit no more than an assessment of the cellular materials which can be labeled by agents which cannot penetrate membranes, thus greatly restricting the amount of useful information obtained.

The microspheres can be utilized to yield a biochemical mapping of the membrane with respect to assessment of surface receptors which can redistribute in the plane of the membrane in response to a matrix containing rigidly displayed ligands. This will be useful in de-
terminating the contributing roles of the restriction of movement of certain surface receptors to oncogenic transformation of cells. Other applications include the isolation of differentiated regions of cell surface membrane, and studies of this nature would be of great utility in areas such as development biology.

The microspheres are synthesized by free radical initiated emulsion polymerization or high energy radiation induced copolymerization of a first ethylenically unsaturated monomer containing a covalently bondable moiety such as hydroxyl, primary amine or carboxyl, and ethylenically unsaturated comonomer having a density differing from the monomer by at least 15 percent and a cross-linking agent to form small, round, microspheres at least 80% of which have a uniform diameter below 5 microns, and preferably below 1 micron, suitably 300 A to 2000 A. The microspheres have a density above 1.3 or below 1.15 g/cc, are hydrophilic, hydrolytically stable, are biocompatible and have a sufficient mechanical strength to be useful as an absorbent in column of film chromatography, gel filtration and permeation, separation and analysis. The microspheres are of well characterized structure, of outstanding purity and the hydrophilic properties, size and mechanical properties can be systematically varied by selection of monomer and polymerization conditions.

The microspherical beads containing hydroxyl, carboxyl or amine groups can be covalently bonded to antibodies and other biological materials and are useful as specific cell surface markers for scanning electron microscopy. The particles are found to bind the hormones, toxins, lectins, and other molecules and have application in the detection and localization of a variety of cell surface receptors. Particles tagged with fluorescent dye or radioactive molecules serve as sensitive markers for quantitative study of cell surface components by covalently bonding lectins, antigens, hormones and other molecules to these spheres, and detection and localization of specific carbohydrate residues. Antibodies, hormone receptors and other specific cell surface components can also be determined. These reagents also have application in highly sensitive radioimmune assays, as visual markers for fluorescent and transmission electron microscopy, for radioactive quantitation of specific cell surface receptors and as potential therapeutic reagents.

Technique for isolation of cell membranes and membrane receptors comprises the steps of covalently bonding an antibody or antigen molecule to the microspheres. The bonded microspheres are then to be added to cells and bind to specific conjugate receptor, antigen or antibody, sites on the cell membrane. The labeled cells are then disrupted into fragments by nitrogen de-compression, homogenization or other standard procedure. The membrane fragments are then centrifuged to equilibrium on linear density gradients. These and other attendant advantages of the invention will become apparent as the invention becomes better understood by reference to the following detailed descriptions.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The total monomer concentration is maintained between 1 to 40% by weight preferably from 3 to 30% by weight of the polymerization mixture. By utilizing low monomer concentration and quick and uniform initiation, as disclosed in copending application Ser. No. 3,634,935, filed concurrently herewith, small microspheres of more uniform diameter are formed.

The first covalently bondable monomer is suitably a primary amine, carboxyl, or hydroxyl substituted acrylic monomer and should comprise at least 10% by weight of the monomer mixture, generally from 20 to 60% thereof. Exemplary monomers are acrylamide, hydroxyl lower alkyl acrylate, amino lower alkyl acrylate, acrylic acid, methacrylic acid or the like. Representative monomers may be selected from compounds of the formula:

$$R^1\text{CH}_2\text{CH}=\text{CHR}_2\text{O}$$

where R$^1$ is hydrogen or lower alkyl of 1-8 carbon atoms, R$^2$ is alkylenne of 1-12 carbon atoms, Z is OH or R$^3$-N=R$^4$ where R$^3$ or R$^4$ are H, lower alkyl or lower alkoxy, 2-hydroxyethylmethacrylate, 3-hydroxypropyl methacrylate, 2-dimethylaminoethyl methacrylate and 2-aminoethyl methacrylate are readily available commercially.

Minor amounts of 0.35%, suitably 10-25% by weight of the monomer mixture may comprise a compatible comonomer such as a lower alkyl methacrylate, acrylic or methacrylic acid, styrene or vinyl toluene.

The cross-linking agent is present in the monomer mixture in an amount from 1 to 10% and is a liquid polyunsaturated compound such as a diene or a triene capable of addition polymerization with the unsaturated group of the monomer. Suitable compounds are low molecular weight liquid polyvinyl compounds such as ethylene glycol dimethacrylate (EGD), divinyl benzene, tri-methylol propane trimethacrylate and N,N'-methylene-bis-acrylamide.

A commercial form (95%) of hydroxyethylmethacrylate (HEMA) and hydroxypropyl methacrylate (HPMA) as supplied, contains small amounts of methacrylic acid, hydroxyalkylmethylmethacrylate and dimethacrylates - ethylene dimethacrylate in HEMA and propylene dimethacrylate in HPMA. HPMA is generally a mixture in which the principal monomers comprise 68-75% of 2-hydroxypropyl and 25-32% of 1-methyl-2-hydroxyethylmethacrylate.

The variable density comonomer is present in the monomer mixture in an amount sufficient to raise or lower the density to the desired range. It is to be realized that the cross-linked microspheres have a greater density than the monomers. The acrylic monomers and comonomers generally have a density of about 0.9 to 1.0 g/cc and they form microspheres having a density of about 1.24g/cc. If one half of the hydroxyethylmethacrylate monomer is replaced with a monomer such as trifluoroethylethylmethacrylate which has a density of 1.16 g/cc, about 30% higher, the resulting microsphere would have a density of about 1.42.

The heaviest known comonomers have a density of about 1.6 g/cc and the lightest about 0.78 g/cc. Thus the minimum amount of variable density comonomer should be about 25% by weight. The maximum amount is only limited by the amount of first monomer and the entire variable density comonomers are provided in the following table.
Emulsion polymerization is conducted at temperatures from about 60° C to 120° C with agitation in presence of an inert gas such as nitrogen or argon in the presence of an emulsifier and free radical initiator. The monomers, emulsifier and inhibitor are introduced into distilled water in a container. The container is immersed in a heated bath. In about 1 hour nearly quantitative yields are achieved. Emulsifier and other ionic impurities are removed from the latex suspension on a mixed-bed ion exchange column and the microsphere particles are then dried. The density of the particles is then determined by centrifugation at 100,000 g for 12 hours on a linear sucrose gradient. The diameter of the particles was measured by transmission and scanning electron microscopy.

The surface active emulsifying agent is preferably present in an amount below 10% by weight of the monomer mixture, typically from 2-5% thereof, to minimize the after treatment for removal of the agent from the microsphere mixture, typically from 2-5% thereof, to minimize the density of the particles is then determined by centrifugation at 100,000 g for 12 hours on a linear sucrose gradient. The diameter of the particles was measured by transmission and scanning electron microscopy.

The surface active emulsifying agent is preferably present in an amount below 10% by weight of the monomer mixture, typically from 2-5% thereof, to minimize the after treatment for removal of the agent from the microsphere suspension. Suitable agents are ionic materials such as sodium dodecyl sulfate (SDS), sodium laurel sulfate, sodium stearate or non ionic materials such as hexafluoropropyl methacrylate and 0.3 g of bis-trifluoroethyl methacrylate were combined with distilled water to form a 3% total monomer solution. 0.12 grams of SDS and 0.9 grams of 2-hydroxethyl methacrylate (HEMA), 0.3 grams of methacrylic acid (MAA), 1.5 grams of hexafluorooctylpropyl methacrylate and 0.3 g of bis-acrylamide were combined with distilled water to form a 3% total monomer solution. 0.12 grams of SDS and 0.012 g of AP were added and the container inhibited with argon was placed in a tumbling container and inserted in a 98° C bath for 1 hour. 400A diameter microspheres in 99% yield having a density of 1.46 g/cc were recovered. Density was determined by means of a cesium chloride density gradient.

Examples of practice follow:

**EXAMPLE 1**

0.9 grams of 2-hydroxethyl methacrylate (HEMA), 0.3 grams of methacrylic acid (MAA), 1.5 grams of hexafluorooctylpropyl methacrylate and 0.3 g of bis-acrylamide were combined with distilled water to form a 3% total monomer solution. 0.12 grams of SDS and 0.012 g of AP were added and the container inhibited with argon was placed in a tumbling container and inserted in a 98° C bath for 1 hour. 400A diameter microspheres in 99% yield having a density of 1.46 g/cc were recovered. Density was determined by means of a cesium chloride density gradient.

**EXAMPLE 2**

The same conditions as Example 1 were followed except that the following monomers were used:

<table>
<thead>
<tr>
<th>Comonomer</th>
<th>Density, g/cc</th>
</tr>
</thead>
<tbody>
<tr>
<td>trifluoroethyl methacrylate</td>
<td>1.16</td>
</tr>
<tr>
<td>Pentafluorostyrene</td>
<td>1.412</td>
</tr>
<tr>
<td>Vinyl ethyl ketone</td>
<td>0.985</td>
</tr>
<tr>
<td>Vinyl ethyl ether</td>
<td>0.76</td>
</tr>
<tr>
<td>Vinyl iodide</td>
<td></td>
</tr>
<tr>
<td>Vinyl bromide</td>
<td>1.5</td>
</tr>
<tr>
<td>Hexafluoropropyl methacrylate</td>
<td>1.16</td>
</tr>
<tr>
<td>Metacycloxymethylpentamethyl disiloxane</td>
<td>0.903</td>
</tr>
<tr>
<td>1,3-Bis (metacycloxymethyl) - disiloxane</td>
<td>0.996</td>
</tr>
</tbody>
</table>

Density of beads produced > 1.41 as determined on a sucrose gradient.

**EXAMPLE 3**

The same conditions as Example 1 were followed except for the following monomer composition:

<table>
<thead>
<tr>
<th>Monomer</th>
<th>Weight, g</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-hydroxethyl methacrylate</td>
<td>0.7</td>
</tr>
<tr>
<td>methacrylic acid</td>
<td>0.7</td>
</tr>
<tr>
<td>trifluoroethyl methacrylate</td>
<td>5.11</td>
</tr>
<tr>
<td>ethylene glycol dimethacrylate</td>
<td>0.49</td>
</tr>
</tbody>
</table>

The density was 1.31 g as determined on a sucrose gradient.

**EXAMPLE 4**

Identical conditions to Example 1 except for the following monomer composition:

<table>
<thead>
<tr>
<th>Monomer</th>
<th>Weight, g</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEMA</td>
<td>1.4</td>
</tr>
<tr>
<td>MAA</td>
<td>0.7</td>
</tr>
<tr>
<td>TFEM</td>
<td>4.41</td>
</tr>
<tr>
<td>EGD</td>
<td>0.49</td>
</tr>
</tbody>
</table>

Density was 1.305 g as determined on a sucrose gradient.

**EXAMPLE 5**

Identical conditions to Example 1 except for the following monomer composition:

<table>
<thead>
<tr>
<th>Monomer</th>
<th>Weight, g</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEMA</td>
<td>2.1</td>
</tr>
<tr>
<td>MAA</td>
<td>0.7</td>
</tr>
<tr>
<td>TFEM</td>
<td>3.71</td>
</tr>
<tr>
<td>EGD</td>
<td>0.49</td>
</tr>
</tbody>
</table>

Density was 1.265 g as determined on a sucrose gradient.

Fluorescent or radioactive tagged beads can be prepared by covalently binding glycine or dansyl-e-lysine by the cyanogen bromide procedure disclosed by Cuatrecasas, 1970, J. Biol. Chem. 245:3059 and as disclosed in copending application Ser. No. 634,935 filed concurrently herewith, the disclosure of which is incorporated herein by reference.

An aqueous suspension of the beads of Example 1 (20-55 gm/ml) is adjusted to pH 10.5 and is activated with CNBr (10-20 mg/ml of suspension) at 25° C. The pH of the reaction mixture is maintained at 10.5 with 1 N NaOH After 10-15 minutes, the activated beads are added to an equal volume of 5mM dansyl-e-lysine or [3H] glycine in 0.2 M carbonate buffer at pH 10 and the suspension is stored for 12 hours at 4° C. Uncoupled reagents are removed by extensive dialysis against several charges of 0.1 M NaCl.

Derivated beads can be prepared by bonding e-aminoacaproylic acid or diaminohapteine to the beads by using the carbodiimide reaction as disclosed by Goodfriend et al; Science (Wash.D.C.) 144:1344. 10 mg of 1-ethyl-3-(3-dimethylaminopropyl)-carbodiimide (EDC) is added with stirring to 5 ml of bead suspension (25 mg/ml) suspended in 0.01 M diaminohapteine or 0.01 M e-aminoacaproylic acid at pH 6-7 and 4° C. After stirring for 2 hours in the cold, the suspension is exhaustively dialyzed against 0.1 M NaCl.

For use in cell surface-labeling experiments, purified goat antirabbit IgG antibodies can be covalently bonded to the beads by either the carbodiimide or glutaraldehyde method. In the carbodiimide reaction, 10 mg of EDC are added to 50 mg of e-amino-caproylic acid...
A method according to claim 1 in which the protein is selected from antibodies, antigens and lectins.

A method according to claim 3 in which the beads are hydrophilic, swellable, porous, uniformly shaped round beads, at least 80% of which have a uniform diameter below 3 microns.

A method according to claim 4 in which the first monomer is selected from acrylamide, hydroxy-lower alkyl acrylates, amino-lower alkyl acrylates, acrylic acid or methacrylic acid.

A method according to claim 5 in which the first monomer is selected from compounds of the formula:

\[ R^1 - \overline{C-C-O} - R^2 - Z \]

where R^1 is hydrogen or lower alkyl of 1-8 carbon atoms, R^2 is alkylene of 1-12 carbon atoms, Z is OH or

\[ \overline{R^1 - N - R^2} \]

where R^1 or R^2 are H, lower alkyl or lower alkoxy.

A method according to claim 6 in which the first monomer is selected from 2-hydroxyethyl methacrylate, 3-hydroxypropyl-methacrylate, 2-dimethylaminomethylmethacrylate and 2-aminoethylmethacrylate.

A method according to claim 3 in which the crosslinking agent is a polyvinyl diene or triene capable of addition polymerization with the first monomer and comonomer and is present in the monomer mixture in an amount from 20-60% by weight.

A method according to claim 8 in which the crosslinking agent is selected from ethylene glycol dimethacrylate, divinyl benzene, trimethyl propane trimethacrylate, and N,N'-methylene-bis-acrylamide.

A method according to claim 2 in which the co-monomer is present in the monomer mixture in an amount above 40% by weight to 80% by weight.

A method according to claim 10 in which the co-monomer contains at least three fluoride atoms.

A method according to claim 11 in which the co-monomer is selected from hexafluoroisopropyl methacrylate, trifluoroethyl methacrylate, pentafluoro styrene, vinyl ethyl ketone, vinyl ethyl ether, vinyl iodide, vinyl bromide, methacryloxy-methylpentamethyl siloxane and 1,3-bis-(methacryloxy-methyl)-disiloxane.

A method according to claim 12 further including the steps of adding the conjugate labeled protein-bead to the mixture, binding the protein to the conjugate and separating the protein-conjugate-bead from the mixture.