

Aug. 11, 1953

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METHOD AND APPARATUS FOR SEPARATION
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Filed March 30, 1951

2,648,636

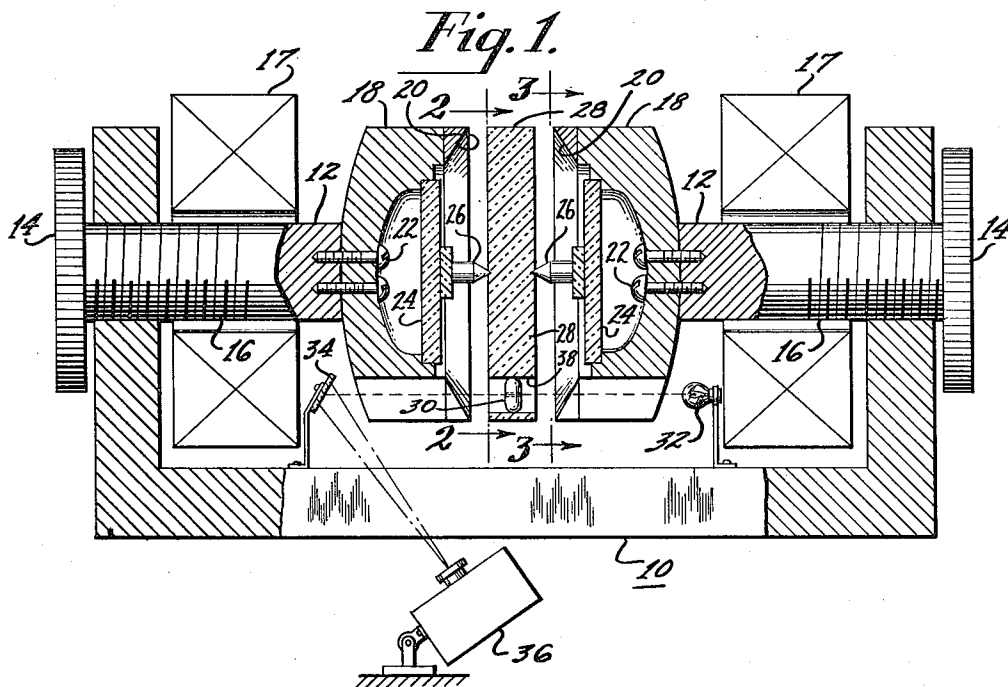


Fig. 2.

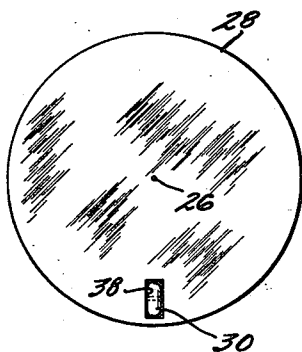
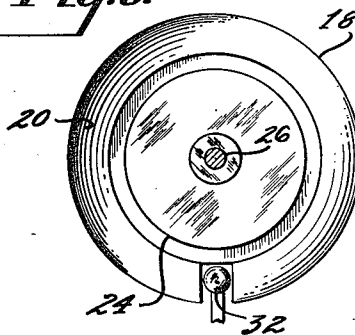


Fig. 3.



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UNITED STATES PATENT OFFICE

2,648,636

METHOD AND APPARATUS FOR SEPARATION OF COLLOIDS IN A COLLOID SOLUTION

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Application March 30, 1951, Serial No. 218,309

6 Claims. (Cl. 252—303)

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The present invention relates to and is an improvement in the art of centrifuging.

The sedimentation of colloids from a colloidal solution may be obtained by the use of a centrifuge or ultra-centrifuge. It has been demonstrated that colloidal particles have an electric charge. For a given substance in a colloidal suspension, the charges on the particles are generally of like polarity. Acceleration of the rate of sedimentation of the colloids in a colloidal solution is obtained by applying a magnetic field to the colloidal solution while it is being whirled in a centrifuge. The magnetic field is applied with a uniform intensity, parallel to the axis of rotation and with a polarity to apply a force to assist the centrifugal force being applied as a result of the rotation. Essentially, the effect of the magnetic field on the charged colloid particle is to make the particle move in the field in a direction dependent upon the polarity of the charge on the particle and the sense or polarity of the magnetic field.

In colloid chemistry, it at times becomes necessary to separate colloids from colloidal solutions wherein the colloid solution contains a mixture of colloids having a different charge to mass ratio and a separation is desired into colloids having the same charge to mass ratio. This separation is not readily effectuated by centrifuging or application of a magnetic field in the hitherto known manner, since this merely results in a deposition of the mixture of colloids having a different charge to mass ratio.

It is an object of the present invention to provide a system and apparatus whereby a complete separation may be effectuated of colloidal mixtures wherein the charge to mass ratio differs.

It also becomes desirable, at times, in colloid chemistry to determine the charge on colloids. It is another feature of the present invention that it permits measurement of the charge on colloids.

Still another object of the present invention is to provide a novel and improved centrifuging system and apparatus.

These and other objects and features of the invention are attained by rotating a centrifuge rotor carrying the colloidal solution between the poles of an electromagnet. The magnetic field is applied parallel to the axis about which the rotor rotates and the magnetic field is non-uniformly applied so that the field intensity varies radially. If the magnetic field sense is properly chosen as well as the range of field intensities, colloidal particles with a charge to mass ratio greater than

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a calculable amount will move centrifugally and be precipitated out at one level of this solution, and those particles with a charge to mass ratio less than the calculated amount will move centripetally and be precipitated out at a different level of the solution. By choosing a magnetic field having a known intensity range and by applying the magnetic field to oppose the effects of the mechanical centrifugal force the colloidal particles in a colloidal solution can be made to deposit out in the solution at a rate or at a level within the solution which is dependent upon the charge upon the colloid.

The novel features of the invention as well as the invention itself, both as to its organization and method of operation, will best be understood from the following description, when read in connection with the accompanying drawings, in which

Figure 1 is a cross-section of an embodiment of my invention,

Figure 2 is a side view of the centrifuge rotor shown in Figure 1,

Figure 3 is a sectional view showing the location of a slot in the pole pieces shown in Figure 1.

Referring now to Figure 1 there is shown in cross-section an electromagnet 10 having a pair of adjustable pole pieces 12. The distance between the pole pieces is adjusted by turning the handles 14 at each end of the pole pieces. This causes the pole pieces 12 to turn in the threaded portion 16 of the U-shaped portion of the electromagnet, thus bringing the pole pieces closer together or further apart. Mounted on the pole pieces are the field coils 17 which are electrically excited for exciting the electromagnet 10. The inner ends of the pole pieces are cup-shaped members 18. The lip 20 of each cup-shaped member effectively provides an annular type of pole face but the actual pole faces 20 themselves are not parallel to each other but are at an angle to each other for reasons which will be made more clear subsequently herein.

The cup-shaped members 18 may be mounted on the pole pieces 12 by two threaded studs 22 to be movable with the pole pieces. A pair of non-magnetic discs 24 are forceably mounted on ridges within the cup-shaped members. Forceably mounted in each of the discs is a rod-like member 26 having its free end shaped to serve as a bearing or supporting a bearing and to support a centrifuge rotor 28. As the pole pieces are moved inward the bearings 26 engage correspondingly shaped holes in the centrifuge rotor 28. The details of mounting the centrifuge on

bearings are well known in the prior art and are not an essential part of the invention.

The centrifuge rotor 28 is shown in Figure 2. It is made of non-conducting and non-magnetic material and carries a small container 30 wherein the colloidal solution is carried to be rotated by the rotor. The size of the pole faces is such as to insure that the magnetic field is applied to the colloidal solution throughout the path it travels while being revolved by the rotor. A slot is left in the two cup-shaped members 18, one of which is shown in Figure 3. These two slots are aligned and, as shown in Figure 1, a light 32 shines through both slots and through the colloidal solution when it is aligned with the slots. This light 32 is reflected by a mirror 34 to a camera 36 by means of which the conditions in the solution may be photographed. The rotor 28 may be driven by a blast of air at its edge if it is so desired. This slot also provides space for the removal of the container 30. A beam of light may be shined through the same, or a smaller slot, and the rate of rotation of the rotor determined from the number of times per second the light is interrupted.

Consider a uniform magnetic field of intensity H , which is applied parallel to the axis of rotation of a colloidal mixture being rotated in a centrifuge. If the sense in which the field acts is properly chosen with regard to the sense of rotation of the rotor and the sign of the charge on the colloid, then a centrifugal force $Hqr\omega - F$ will act on the particles of the colloid where H is the magnetic field strength, q is the charge on the colloid, r is the radius to the point at which the field acts, ω is the angular velocity of the rotor, and F is a force due to the displacement of other charges in the suspension.

The force $Hqr\omega$ may be large compared with the force F and the mechanical centrifugal force which may be expressed as

$$\frac{4}{3}\pi a^3(\rho - \rho_0)\omega^2 r$$

a =radius of colloidal particles

ρ =density of colloidal particles

ρ_0 =density of liquid in which particles are suspended

The complete equation of the motion is

$$6\pi\eta a \frac{dr}{dt} = \frac{4}{3}\pi a^3(\rho - \rho_0)\omega^2 r + Hq\omega r$$

or

$$\frac{1}{\omega r} \frac{dr}{dt} = \frac{2a^2(\rho - \rho_0)}{9\eta} \cdot \omega + \frac{Hq}{6\pi\eta a} - \frac{F}{6\omega\pi\eta a}$$

where η =viscosity of the liquid in which the colloid is dispersed. If, therefore, the rate of sedimentation

$$\frac{dr}{dt}$$

is measured for different ω with H fixed or different H with ω fixed, it is possible to deduce q from the measurements, F being determined by the methods at present used in electrophoretic measurements.

If H is made to increase radially and the sense of the applied magnetic field is chosen so that the force $Hqr\omega$ acts centripetally, there will be a value for which the rate of sedimentation,

$$\frac{dr}{dt} = 0$$

and therefore the mechanical centrifugal force equals the magnetic centripetal force. There-

fore, if a magnetic field is applied which varies in intensity from a maximum to a minimum from the outer portion of the colloidal solution being centrifuged to the inner portion, the colloidal particles in the intense magnetic field are driven inward by the magnetic centripetal force. Those colloidal particles in the less intense magnetic field are driven outward by the mechanical centrifugal force. A layer of colloidal material is thrown to the sides of the cell at the boundary region where the two forces are substantially equal. The location of this layer for a given colloidal solution is dependent upon the mass to charge ratio of the colloidal particles. This layer is represented in Figure 2 as the line of dots 38 across the carrier of the colloidal solution. The layer and its location may be photographed using the camera shown in Figure 1 to take a picture of the image in the mirror formed by the light shining through the slots in the pole pieces when the solution is aligned with the slots. The radial increase in the applied field strength is obtained by shaping the pole faces 20 shown in Figure 1 to have an angle to each other rather than being parallel.

The field strength at the colloidal layer is readily determined as well as the radius from the axis of rotation to the layer. The angular velocity of the rotor at the colloidal solution is measurable. The colloidal density, viscosity of the liquid in which the colloids are dispersed, as well as its density and the radius of the colloidal particles, are all measurable using techniques which are well known in colloid chemistry. By the substitution of these measurements into the equation of motion given above, a solution for the charge on the particle may be found. Different colloidal particles in a solution will form different layers in the solution if the range of the centripetal force provided by the non-uniform magnetic field is sufficient to balance the centrifugal force applied.

In order to separately precipitate mixed colloids having different charge to mass ratios, the strength of the magnetic field may be selected and applied so that particles with a greater charge to mass ratio than can be deterred by the centripetal force move outward under the effect of the centrifugal force and the particles with the smaller charge to mass ratio are moved inward by the centripetal force. Thus, a complete separation of the particles in the colloidal mixture is effected. The field strength may be determined by making a few trial variations. Alternatively, the velocity of the centrifuge rotor may be varied until a double precipitation is seen to occur.

In colloidal solutions, where the colloid carrier or liquid is heavier than the colloidal particles, separation by centrifuging results in the colloidal particles being moved inward toward the axis of rotation. In such cases the pole faces are altered to have an angle opposite to the one shown so that the magnetic field increases radially inward instead of outward and the magnetic force is applied to urge the colloidal particles inward instead of outward. In either situation, where the liquid is heavier or lighter than the colloidal particles, the sense or polarity of the applied magnetic field is determined by the polarity of the charge on the colloidal particles.

From the foregoing description, it will be readily apparent that there has been provided a novel and improved centrifuging system for separating colloidal particles from colloidal solu-

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tions and for measuring the charge on the particles. Although a single embodiment of the present invention has been shown and described, it should be apparent that many other embodiments are possible, all within the spirit and scope of the invention. It is therefore desired that the foregoing description shall be taken as illustrative and not as limiting.

What is claimed is:

1. A system for concentrating electrically charged colloids having a known density and diameter in a colloidal solution of a known density and viscosity, comprising means including a rotor to apply a centrifugal force to said solution at a known angular velocity, means including an electromagnet to apply to said solution a known non-uniform magnetic field at right angles to said centrifugal force and with a sense to apply a centripetal force to said colloids whereby said colloids are concentrated at a level within the carrier of said colloids dependent upon the charge to mass ratio of said colloids.

2. Apparatus for concentrating electrically charged colloids in a colloidal mixture comprising means including a rotor to rotate said colloidal mixture about an axis at a known angular velocity to apply a centrifugal force thereto, means including an electromagnet to apply to said mixture a magnetic field parallel to the axis of rotation and having an intensity that ranges from a maximum to a minimum through said colloidal mixture, the polarity of said magnetic field being such as to apply a centripetal force to said colloids whereby said colloids are concentrated at a level within the carrier of said colloids dependent upon the charge on said colloids, and means to measure the distance of said colloidal concentration from said axis.

3. Apparatus for effecting a colloidal mixture separation comprising a centrifuge rotor having a container therein wherein said mixture is carried, and an electromagnet having a pair of substantially annular-shaped poles positioned on opposite sides of said rotor to provide a magnetic field parallel to the axis of said rotor over the path traveled by said container in said rotor, each of the opposite pole faces of said electromagnet being formed with an annular, outwardly tapered portion, whereby said magnetic field

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varies from a minimum intensity to a maximum intensity through said colloidal mixture.

4. Apparatus for effecting a colloidal mixture separation comprising a centrifuge rotor having a container therein for carrying said mixture, and an electromagnet having a pair of substantially annular shaped poles positioned on opposite sides of said rotor to provide a magnetic field parallel to the axis of said rotor, the inner and outer diameter of said annular-shaped poles being larger than the inner and outer diameter of the path traveled by said container on said rotor, the opposite pole faces of said pair of poles being at an angle to each other, whereby said magnetic field varies from a minimum intensity to a maximum intensity through said colloidal mixture.

5. The method of effecting a separation of colloids having different charge to mass ratios from a colloidal solution comprising applying a centrifugal force to said mixture, and applying a magnetic field to said mixture at right angles to said centrifugal force with a sense to apply a centripetal force to said colloids and with a field intensity to overcome the centrifugal force applied to certain ones of said colloidal particles whereby said certain ones of said colloidal particles are concentrated out at one level of said colloidal solution and the remaining ones of said colloidal solution are concentrated out at a different level of said solution.

6. The method of effecting a separation of colloids of known density and diameter in a colloidal solution of known density and viscosity comprising applying a centrifugal force to said solution at a known angular velocity and applying to said solution a magnetic field having a known non-uniform field strength at right angles to said centrifugal force and with a sense to apply a centripetal force to said colloids whereby said colloids are concentrated at a level within the carrier of said colloids dependent upon the charge to mass ratio of said colloids.

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