Interpreting the Appearance of Dispersed Systems: II. A Guide for Surfactant Systems

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ABSTRACT

We first analyze how color and transparency are perceived. Drawing on principles of light scattering investigated in Part I, we suggest simple rules and procedures in a diagnostic form for visually observing fluid surfactant systems to estimate sizes of dispersed particles. Rules and procedures are organized into a guide, the use of which we illustrate by observing certain important surfactant systems. We conclude that it is possible to estimate particle sizes in the Rayleigh, Rayleigh-Debye-Gans, and Mie scattering regimes from such observations alone.

INTRODUCTION

Observing fluid surfactant systems with the naked eye is an important factor in screening surfactant systems for many types of applications and for scientific studies. With such observations, surfactant systems are classified as solutions, microemulsions, macroemulsions, dispersions, etc., although classification may be no more than tentative.

In Part I (1), we tested certain literature rules (2,3) for interpreting appearances against spectroturbidimetry and light scattering measurements on model dispersions of polymer latex microspheres. We found that those rules are unreliable for correctly interpreting the appearance of many important disperse systems. We suggested more general rules and examined them systematically.

In this paper, we analyze the perceptions of color and transparency. Based on this analysis and the rules put forward in Part I, we propose a guide for surfactant systems in a step-by-step diagnostic format. We demonstrate the applicability of this guide to certain important surfactant systems we have researched in detail elsewhere (4-6).

COLOR AND TRANSPARENCY

Light is electromagnetic radiation detectable by the average human eye, i.e., with wavelengths in the range 350-780 nm or, for a reasonable sensitivity, in the range 400-700 nm. It is well known that ordinary white light (e.g., direct sunlight) can be analyzed by means of a prism into several distinct bands of wavelengths, each of which gives a characteristic sensation called color. A 'spectral' color is one which consists of a narrow band of wavelengths and remains unchanged if analyzed further.

The visible range can be roughly divided into six familiar color bands, each of which merges into its neighbors (see Table I).

The human eye cannot analyze light into its component wavelengths. The sensation induced by a spectral distribution of light—energy distribution per unit wavelength—reaching the eye is an overall one: quite different spectral distributions can give the same sensation that a pure spectral color does (see the law of color perception later). For example, a clear brilliant yellow color can be obtained by mixing appropriate amounts of red and green light beams. The perception of color has, therefore, no direct physical meaning but psychophysical meaning, which has some correspondence to physical quantities (7). A marvelous account of the physics, physiology, and psychophysics of color vision is given by Feynmann et al. (8).

What is called brightness of a light source corresponds to the luminance. Luminance, in turn, is defined as the radiance (W/m^2) reaching the eye times the eye sensitivity. The eye sensitivity depends on the wavelength; a (semi-) quantitative measure of it defined for an average observer is called luminosity.

What is called hue, or main color (if any), corresponds to the dominant wavelength (if any) of the incident radiation. What is called saturation of color corresponds to the purity or monochromaticity of light. Because white, black and gray have no dominant wavelength, they are not colors in the regular sense and they are called hueless or achromatic. Of a certain spectral distribution the perceived hue and saturation lumped together are called chromaticity (chroma is the Greek word for color). An operational definition of dominant wavelength is that spectral color which would have to be mixed with an appropriate amount of white light in order to match the chromaticity of a given light source. The following degrees of decreasing chromaticity may be distinguished: brilliant (spectral color or mixed color matching a spectral color), bright (not to be confused with high luminance), moderate, pale and light. Faint refers to only slight discernible hue.

The theory of color vision of Young and Helmholz assumes the existence, at the retina of the eye, of three cone-nerve combinations, each of which has a different spectral response. The response can be considered analogous to that of three photomultipliers with different cathodes and dynode systems receiving the same signal but responding differently (8). The theory seems to lack supporting anatomical evidence but it is simple and ade-

TABLE I

Colors of the Visible Range of Light

λ_0 range (nm)	Color
400-450	violet
450-500	blue
500-570	green
570-590	yellow
590-610	orange
610-700	red

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quate. The three cone-nerve combinations give three characteristic stimuli which are "processed" in the brain to give an overall sensation of color.

The fundamental law of color perception states that almost all colors can be produced by a combination of three colored sources or lights called primaries. These primaries are most conveniently, but not uniquely, chosen from the midde and near each end of the visible spectrum: namely, red, green, and blue. The amounts of the three primaries needed to produce a particular optical sensation are called the tristimulus values, X, Y, and Z (8). The method has been standardized using standard sources and an average response of observers. Given a spectral energy distribution from absorption or scattering, the tristimulus values are calculated and the color predicted. Two ratios of the tristimulus values, x and y ($x \equiv X/(X + Y + Z)$) and $y \equiv Y/(X + Y + Z)$), are sufficient to predict the chromaticity of the source, namely its hue and its saturation, whereas the scale factor characterizes the brightness or luminance. The response of the eye to different wavelengths is different at high light intensities of, say, an average reading room and at low light intensities, i.e., in the dark. At high light intensities the average eye has maximum sensitivity at 450 nm and at low intensities at 510 nm (8). The dark-adapted eye has a much higher sensitivity, but its ability to distinguish colors is weaker. Thus the eye has a quite selective and nonlinear response, although, as mentioned previously, there is a certain correspondence between physical parameters of spectral distribution and brightness and sensations.

A substance may appear colored if it absorbs or scatters light. Usually the absorption is selective with respect to wavelength. Thus, when white light illuminates a solution which absorbs but does not scatter light, the solution appears colored as a result of selective loss of intensity of some wavelengths. However, if the absorbance at some wavelengths is small, ca. 1 or less, those wavelengths pass through the sample but with a decrease in their intensity. The optical information carried by those wavelengths about an object behind the sample is not 'scrambled' and one can 'see through' the sample. The sample is termed clear or transparent, whether it is colored or not. There is, of course, a practical limit on the level of transmitted intensity which can still be detected and carry the information conveyed by the intensity incident to the sample. If the absorbance due to absorption over all visible wavelengths is 2 or more, as in a crude oil or in a concentrated aqueous solution of potassium permanganate, then one cannot see through the sample, even if it does not scatter. However, this is not a serious problem in most systems of interest, because they do not absorb strongly at all wavelengths and the absorbance can of course be decreased by shortening the path length. How to interpret observations of some dye solutions in terms of the measured absorbance spectra is explained in Reference 1.

If the system scatters light, whether it absorbs or not, then, depending on the type of illumination and the observation, some of the scattered light will reach the eyes of the observer together with some transmitted light, and the information perceived will be scrambled. If light passes through, the sample looks slightly cloudy or hazy, and one can resolve details of an object by looking at it through the sample, the sample is translucent. If one can see an object in outline but cannot resolve details, the sample is turbid. If one cannot see anything which lies behind the sample (at its umbra, preferably), then the sample is opaque.

Light scattered by aggregates or particles carries information about these aggregates or particles. In particular, it provides clues about their size and refractive index (1,7). If this information is not excessively 'scrambled' along the path length by subsequent scattering, i.e., if there is not excessive multiple scattering, then the qualitative observations can be interpreted on the basis of the theory of single scattering.

The ability of the eye to detect scattering depends on the background illumination. For ordinary white light, apparent absorbances ($A \equiv \log_{10} (I_0/I)$, where I/I_0 is the % transmittance) larger than ca. 0.05 (transmittances less than 90%) are detected as a slight hue in the case of absorption or as a slight bluishness or haziness in the case of scattering. Larger apparent absorbances are detected more easily and information is more readily interpretable with translucent to turbid samples which have apparent absorbances due to scattering between 0.05 and 2, or better, between 0.1 and 1 (1), and absorbance due to absorption no more than 1, averaged over wavelength. Thus observations of scattering, at ordinary illumination, are possible only when there is substantial multiple scattering (1). The absorbance can be adjusted by decreasing the path length, as by tipping the vial containing a liquid system, or by transferring it to vials with smaller or larger diameter as necessary. We caution against diluting surfactant systems because the microstructure of liquid phases and the distribution of equilibrium aggregates such as micelles or of suspended particles may change in ways that are not apparent and that may remain unknown.

The following examples illustrate important principles of light scattering detailed in Reference 1:

(a) If the refractive index n_s of aggregates or particles equals that of the surrounding medium, there is no scattering.

(b) For a surfactant with $n_s = 1.45$, a dispersion of small surfactant particles of given concentration would scatter $0.0144/0.0009 = 16$ times more in water ($n_w = 1.33$) than in hexadecane ($n_h = 1.42$), because according to Equations 7 and 8 in Reference 1,

$$(n_s - n_w)^2 = (1.45 - 1.33)^2 = 0.0144$$

and

$$(n_s - n_o)^2 = (1.45 - 1.42)^2 = 0.0009$$

Therefore, it is crucial to have an estimate of the refractive index difference to interpret visual observations accurately.

(c) Air is transparent, for even fairly long path lengths, because the absorbance is much less than 0.05 at all wavelengths; however, the atmosphere over long distances, e.g., the blue sky, is translucent.

(d) From Figure 1A, Reference 1, one gets with path length 1 cm and monochromatic light of wavelength (in vacuo) $\lambda_0 = 436$ nm, an absorbance $A = 0.065$ for just 0.005 wt% in water of polystyrene latex microspheres of size 910 Å and apparent molecular weight 200,000,000. This sample looks slightly opalescent. Therefore, very small concentrations of large particles are detectable, and the larger the size the lower the limit of detectable concentrations.

(e) Conversely, ordinary pure solvents, molecular solutions, and solutions of small micelles scatter very little and are transparent over path lengths up to 500 cm and more. Huisman (9) measured the following absorbances with wavelengths λ_0 = 436 nm and path length 1 cm: A = 0.000017 for pure water; the sample looks transparent. A = 0.00022 for 0.5% aqueous SDS with 1.7% NaCl, a solution that contains mostly micelles of molecular weight 35,400 or 123 molecules per micelle. The sample looks transparent. In order to observe opalescence, i.e., to detect scattering visually, a path length of at least 0.05/0.00022 = 230 cm is needed.

(f) Because intensity is proportional to concentration c times molecular weight M, i $\propto$ cM, (Equation 7, Reference 1), or i $\propto cd^3$ for spheres, a given concentration (in g/cm^3) of material dispersed as spherical particles of 500 Å scatters $(500/50)^3$ = 1000 times more than the same concentration dispersed as particles of 50 Å diameter. Micellar solutions containing swollen micelles, e.g., oil-swollen micelles in aqueous solution, may have particles large enough (larger than 300 Å or so) to produce observable turbidity at concentrations as low as 0.001 g/cm^3 at a path length of 1 cm.

(g) Some mixtures of nonabsorbing materials may appear colored. This is simply the result of the wavelength dependence of scattering (1,7). This wavelength effect depends on the particle dimensions and the refractive index contrast. The intensity of scattered light also depends on the scattering angle, which is the angle between the direction of observation and the direction of illumination. For this reason, the distribution of light intensity per unit wavelength of light scattered depends on the scattering angle. Since the perception of color depends on that distribution of intensity, different colors can be perceived at different scattering angles. This fact provides us with an easy way to detect Rayleigh and Rayleigh-Debye-Gans scattering. As explained in Reference 1, in translucent samples with bluishness of scattered light is an indication of small particles, 0.5 μm or less, that fall in the Rayleigh or the Rayleigh-Debye-Gans scattering regimes. Orange-red colors of transmitted light are an indication of small particles, 0.1 μm or less (Rayleigh scattering). If one sees a haziness, and no color, most of the scattering comes from particles larger than 0.5 μm (Mie scattering) (10).

The above rules hold approximately, at best, if the system is turbid or milky (1). Whether turbid or not, interpretation of colors and translucency is more complicated if the sample absorbs light. However, the color of an intrinsically colored sample which also scatters can differ from the intrinsic color and can vary with the scattering angle. Thus the scattering regimes, especially the Rayleigh regime, can be detected even in a colored sample (Figs. 7A and 7B in Ref. 1).

In summary, color—both hue and saturation—and degree of translucency are the important optical properties of fluid systems. Observations of these properties, if properly interpreted, can provide qualitative information about the state of aggregation or state of dispersion in the fluid.

PROCEDURE AND GUIDE

Observations are more meaningful if the solution, microemulsion, or dispersion of interest is known to be at equilibrium or in metastable equilibrium. Moreover, for concentrated microemulsions the inferences are less precise (11). The way of preparing the system might govern its final appearance, because it may determine the sizes of dispersed particles or aggregates (Fig. 1). It may be advisable to equilibrate two components prior to the addition of the third, the three prior to the addition of the fourth, and so on. If the system appears to change upon further stirring or otherwise with time, it is desirable to record the changes while waiting as long as necessary for the system to stop changing. Possibilities of ambient temperature variation, evaporative loss, oxidative degradation, light sensitivity, etc., need to be checked.

Distinct layers are identified when they are separated by well-defined interfaces. These interfaces must be carefully detected by several criteria, such as smoothness, shininess, or total internal reflection at some angle, and distinguished from graded phases, flocs, etc. In practice, the presence of interfaces can be obscured by emulsions next to them, by proximity to critical points, or simply by dirt particles. The number of layers is the number of transverse liquid/liquid interfaces plus one.

In counting the number of layers or apparent phases, one should take into account the not uncommon reluctance of dispersed phases to settle and coalesce. Centrifugation and ultracentrifugation are important tools for testing this, although a centrifugal field can alter the apparent phase behavior (12). Before accepting an unchanging appearance over days, weeks, or even months as signaling an equilibrium state, one has to try different orders of mixing. If one still has any doubt, one must use heating-cooling cycles or freezing-thawing treatments as checks for the history-independence, which is the hallmark of equilibrium.

One should take pains to avoid introducing dust and other extraneous particles into the system. Vials should be cleaned and filled carefully. It is desirable to avoid fingerprints and labels on the outside of the vials.

For observing a visually homogeneous sample, by which is meant a liquid that appears as a single layer, it is best to fill the vials to a standard height three times the vial diameter, in order that observations can be made at two path lengths differing by a factor of three. For systems with two or three apparent layers, including both transparent and extremely turbid ones, it is useful to observe the same compositions in vials of different diameter, so that the dependence on path length can be seen.

The suggested procedure is to answer a sequence of diagnostic questions (Tables II and III). A series of possible answers is listed below and one can underline or mark the most appropriate ones. The implications of each answer are indicated, followed by either another clarifying question or a hint about interpreting the particular observation or series of observations in terms of the number of phases present and the size of particles or aggregates. The observer should record details as called for in the suggested procedure and should be sure to record any additional observations not covered in the guide.

Since the unaided eye is a poor detector of polarization, some instrument is required to determine the state of polarization of scattered light, which can provide clues about particular size, or shape, or both (1). Use of such instruments falls outside the simple rules for quick and careful visual observations with the unaided eye at ordinary laboratory illumination.

TABLE II

Diagnostic Guide to Visual and Microscopic Observations of Surfactant Systems

Date:
Name:

A. Report the following information:
   I. Materials used: names, overall amounts, composition, and appearance, especially color.
   II. Procedure of system preparation:
      i. order of mixing or layering;
      ii. stirring method, apparatus, vessel, time;
      iii. thermal treatment and temperature.
   III. Visually resolvable particles or droplets:
      If no, go to IV.
      If yes, estimate amount:
         estimate size;
         describe (shape, texture, turbidity, color);
         sketch position.
   IV. Number of visible discernible liquid/liquid transverse interfaces:
      Move the eye relative to the level of the sample vertically). Is there an angle at which there is shininess or total internal reflection? If yes, then there are two or more layers (number of such interfaces plus one); go to V(i). If no, there is one homogeneous layer; go to V(ii).
   V. Number of visible discernible layers.
      i. If one, does appearance change upon gentle stirring?
      If no, 1 homogeneous layer; go to V.
      If yes, 1 inhomogeneous layer;
         any gradient in turbidity? If no, go to B.
            If yes, two phases; sketch system and go to C.
      ii. If two or more, sketch system.

B. For each homogeneous layer, characterize its appearance.
   I. Transparent (or clear); if so, compare with water in similar vial; is sample less clear than water?
      If yes, scattering indicates that some particles may be present. _____
      If no, use two long (~20 cm) volumetric cylinders and compare with water; is sample less clear than water?
         Yes.
         If no—one phase but check C.
   II. Translucent; is any bluishness (opalescence) detectable by observing sample from different angles?
      If no, does it look hazy or foggy?
         If yes—Mie scattering; large particles or droplets, size 0.5 μm or more.
         If no—moderate size particles, 0.5 μm or less.
            If yes, does it look orange-red or yellow to transmitted light?
            If no, try sunlight and answer again:
               If no — Rayleigh-Debye-Gans scattering, size 0.1-0.5 μm.
               If yes — Rayleigh scattering, size 0.1 μm or less.
            If not sure, go to C.
   III. Turbid or milky: Can you see details of an object which is placed behind the sample, at its shadow, its umbra rather than its penumbra? The object is to be held at most a few cm from the sample.
      If yes, go to C.
      If no, use thinner and thinner vials or droppers until you see through; then go to II.

C. If layer is inhomogeneous, or appearance changes upon shaking, or homogeneous layer is translucent to milky, it may be a two- (or more) phase dispersion:
   Put a drop on a glass slide and observe through the light microscope, at ordinary setup (OS) and crossed polars (CP) (beware of evaporation; use capillary or coverslip).
   Are any particles discernible?
   If no, is there light coming through CP?
   If yes, increase magnification and repeat. Are any particles visible?
   If no, the layer is most probably one phase.
   If yes, go to B-II.
   If yes, report set-up, final magnification, size, shape, and texture of particles; take a photograph if possible.

D. For each homogeneous layer, report about its color the following:
   hue, e.g., blue, yellow, etc.; recall that gray, white and black are not colors;
   saturation, faint, light or pale, moderate, bright, or brilliant.
   Is color different when the sample is viewed from different angles?
   If no, is any of the pure materials used colored?
      If no—scattering, go to B-II.
      If yes and layer is clear—no scattering, go to B-I.
   If yes, is any of the pure materials used colored?
      If no—certainly scattering, go to B-II.
      If yes—scattering, mixed with absorption (consider predicting color based on tristimulus values); fluorescence is possible, too.

USING THE GUIDE IN CERTAIN SURFACTANT SYSTEMS

Surfactant dispersions, Figure 1, can look quite similar to dispersions of polymer latex microspheres. Details of observations and photography are given in Reference 1. Such comparisons suggest the use of the latex dispersions to standardize observations of translucency and colors by different observers and with varying conditions of illumination.

Moreover, size estimates can be obtained without any measurement at all. In Figure 1A, the sonicated aqueous dispersion of 1.29 wt% surfactant Texas #1 (sodium *p*-(1′-heptylnonyl)benzenesulfonate) looks clear to translucent. Its colors are bluish by scattered light and bluish or yellowish by transmitted light (the latter colors are not shown in the photograph). This appearance indicates unequivocally that sizes of the surfactant particles are smaller than 1000 Å (0.1 μm), and further that the maximum possible number of particles present of sizes larger than 1000 Å is a negligible fraction of the total. By com-

TABLE III

Diagnostic Guide in a Condensed Form

Date:
Name:

A. Report the following information:
   I. Materials used: overall amounts, chemical characterization, appearance, and especially color. Total composition of system—wt% or vol%.
   II. Procedure used for system mixing or layering, stirring details, and thermal treatment and temperature used; keep system isothermal for several hours at least after preparation is completed.

B. Make a sketch of vial indicating dimensions (cm). Record number of well defined interfaces and layers separated by interfaces. For each layer, record whether it is homogeneous or not in appearance. Also record any visible particles present and their location. Also record the layer's appearance, color, homogeneity of color, and the dependence of any color on the direction of observation. Indicate whether any layer becomes more turbid by gentle shaking. Record anything else that seems pertinent.

C. Recapitulate observations. Decide on number of phases, equilibrium or not, with a short description in terms of dominant component, color, appearance, particles, and other scattering features.

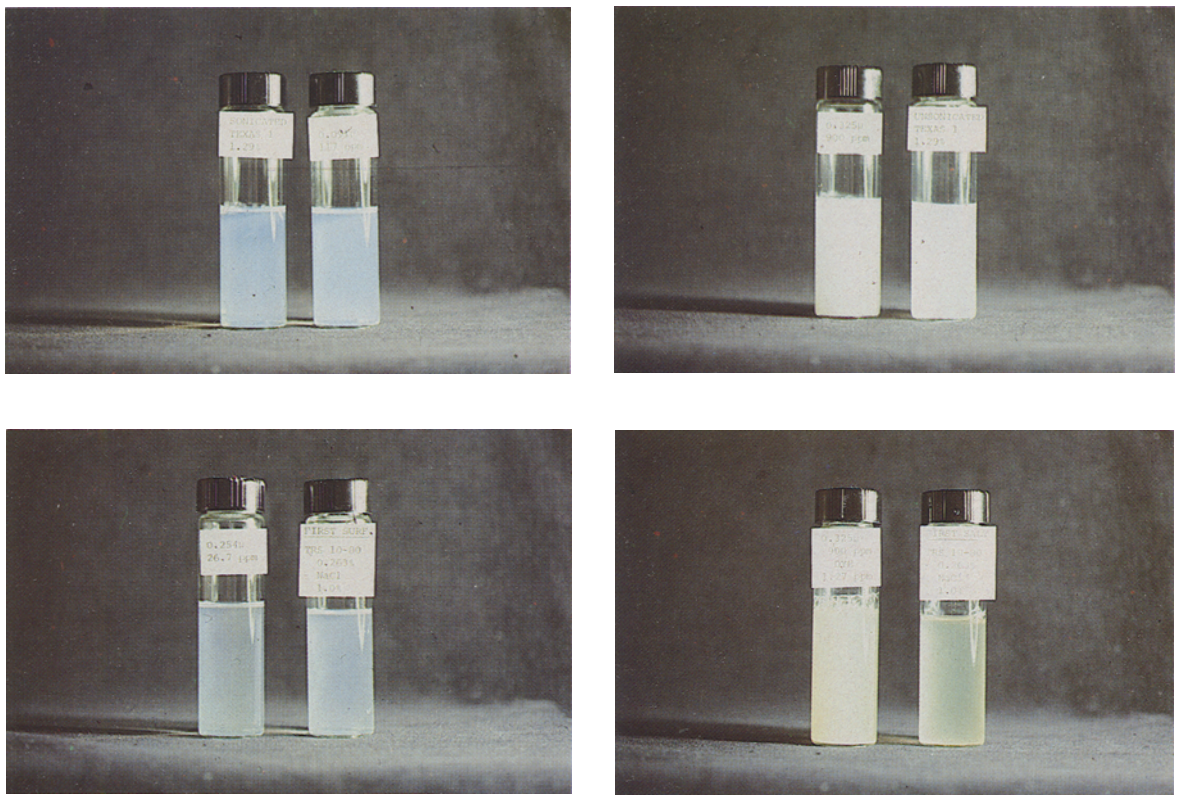

FIG. 1. Photographs of aqueous surfactant dispersions vs model dispersions of polymer latex microspheres. Texas #1 stands for the sodium *p*-1'-heptylnonyl) benzenesulfonate surfactant (4). TRS 10-80^{TM} is the commercial name of the petroleum sulfonate surfactant manufactured by Witco (5). All concentrations are w/w. Upper left: sonicated despersion of 1.29% Texas #1 in water vs a 117 ppm dispersion of 0.091 μm microspheres; Upper right: 900 ppm of 0.325 μm microspheres vs unsonicated 1.29% Texas #1 in water; Lower left: 26.7 ppm of 0.254 μm microspheres vs 0.263% TRS 10-80 in 1.0% aqueous NaCl; this sample was produced by first dissolving the surfactant and then adding aqueous NaCl; Lower right: 900 ppm of 0.325 μm particles with 1.27 ppm methyl red dye added vs the previous TRS 10-80 sample but prepared with the opposite order of mixing (first salt then surfactant).

paring the surfactant dispersion side-by-side with the dispersion of 117 ppm microspheres of size 0.091 μm, it is seen that the scattering is about the same. Thus, the scattering efficiency, A/c, of the surfactant particles is 110 times smaller than that of the 910 Å microspheres, Since in this size range $i \propto (n - n_0)^2$ and $i \propto d^3$ (1), and since $(n - n_0)/c = 0.25$ cm^3/g for the polymer microspheres (13) and $(n - n_0)/c = 0.17$ cm^3/g for the surfactant (14), the size of the surfactant particles is estimated to be ca. 270 Å, if the particles are rigid spheres. The estimate is increased slightly to 330 Å, if the surfactant particles are vesicular, i.e., each consists of a fluid-filled cavity surrounded by a surfactant membrane, as explained in Reference 6. Even though this estimate ignores interparticle interactions, it is in excellent agreement with the estimate from absorbance measurements, which also ignore such interactions, and both agree with electron microscopy results (6).

Figure 1B shows that the appearance and scattering colors of the unsonicated 1.29% Texas #1 sample are about the same as 990 ppm of 0.325 μm PMMA particles. Thus sonication must have decreased greatly the particle size. Figures 1C and 1D show how strongly the appearance and thereby the size of dispersed particles depend on order of mixing of Witco's TRS 10-80 (which is a commercial petroleum sulfonate surfactant) and NaCl in water (see also Fig. 3D below). The first-surfactant-then-salt sample exhibits Rayleigh-Debye-Gans type scattering (Fig. 3C). Since, however, the concentrations differ by a factor of 100, the scattering efficiency of the surfactant sample is 100 times less on the average than that of the polymer sample. If the sizes were uniform in the surfactant sample, they would be ca. 0.08 μm (estimated from $100\times(0.15/0.25)^3\times 0.254$ μm = 0.08 μm). But then the sample would look bluish like a Rayleigh dispersion. The conclusion is that the sample contains a substantial amount of large (Mie and Rayleigh-Debye-Gans) particles and that in order to scatter so efficiently the sample must contain a substantial amount of particles smaller than 0.08 μm. Indeed, micron-size particles were detected in the microscope, indicating that Mie scatterers were indeed present; moreover the bluishness is consistent with Rayleigh particles being present also.

Figure 2 illustrates certain important features of the phase behavior of Texas #1 in water and brine. The 0.029% sample looks transparent and is below the solubility limit which is ca. 0.06% (4). The 0.096% sample after being shaken looks transparent; closer examination reveals some visible particles which flocculate and settle slowly. The 1.29% sample is a turbid dispersion. Figure 2B reveals a dramatic dependence of the appearance of dispersions on salinity. Although the particles in 3% brine look solid-like, they are liquid crystalline, as found by polarizing microscopy and ^{13}C NMR, just as are the particles in the more stable dispersions at 0 and 0.3% NaCl (4).

In Figure 3, samples of aqueous solutions and dispersions of TRS 10-80 are shown. The absorption by the sample is significant at concentrations down to ca. 0.1 wt%

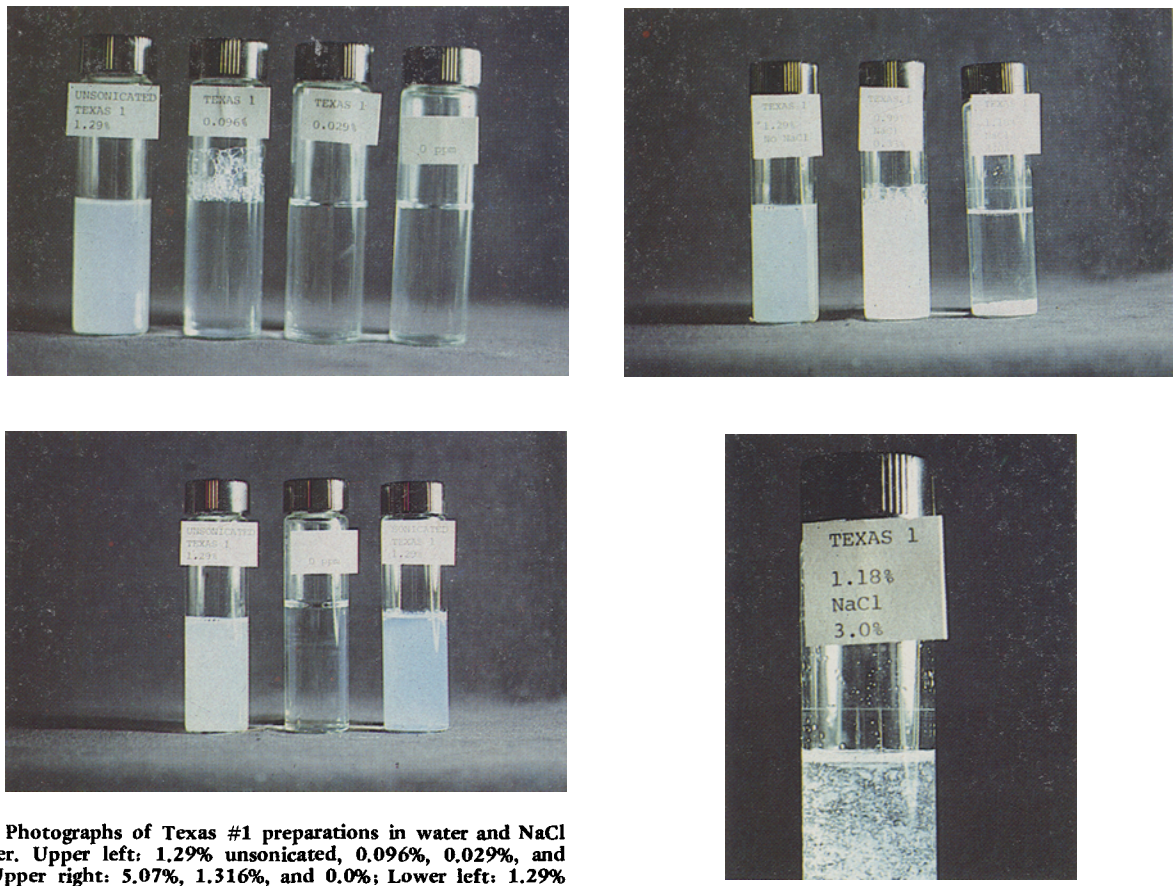

FIG. 2. Photographs of Texas #1 preparations in water and NaCl salt-water. Upper left: 1.29% unsonicated, 0.096%, 0.029%, and 0.0%; Upper right: 5.07%, 1.316%, and 0.0%; Lower left: 1.29% unsonicated, water (0 ppm), 1.29% sonicated; Lower right: 1.18%-3.0% salt.

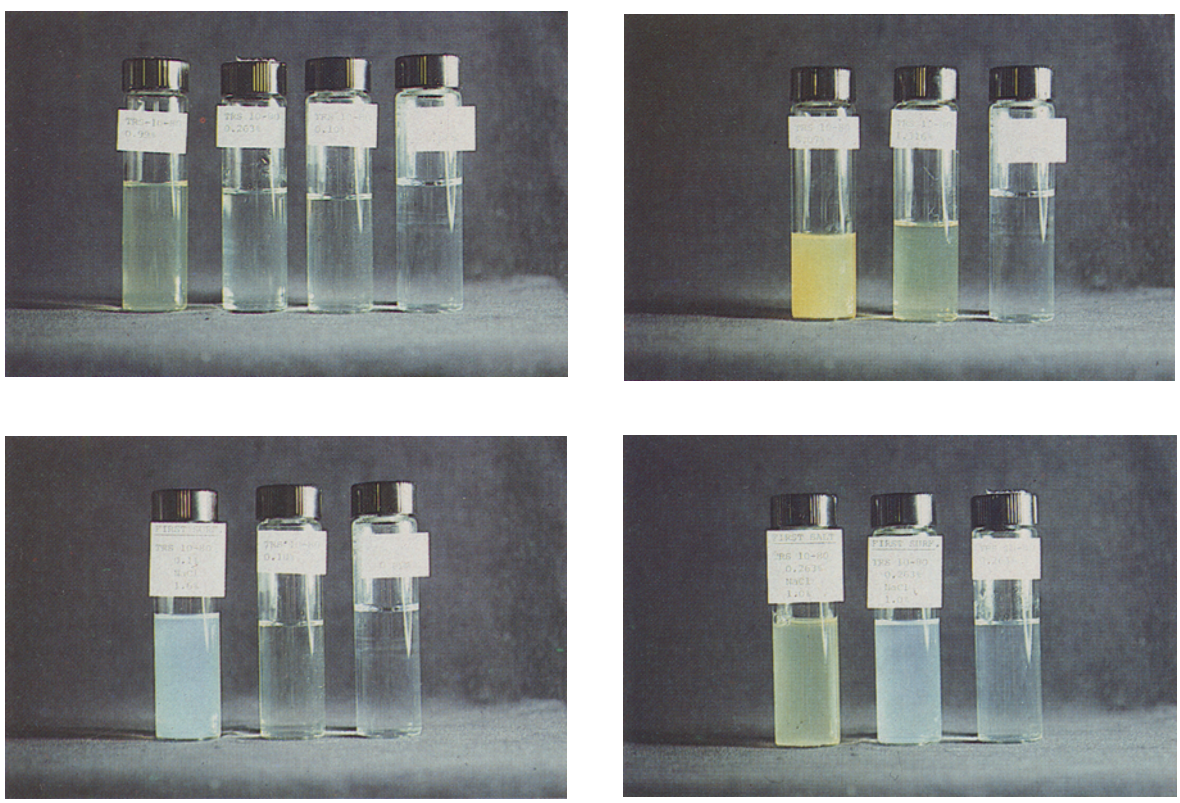

FIG. 3. Photographs of TRS 10-80 preparations in water ans salt water. Upper left: 0.99%, 0.263%, 0.1% and 0.0%; Upper right: 5.7%, 1.316%, and 0.0%; Lower left: 0.1% with 1.6% NaCl with surfactant mixed first, 0.1% with no salt, and 0.0%; Lower right: 0.263% with 1% salt with salt mixed first, same with surfactant mixed first, and 0.263% with no salt.

at 2 cm path length. The brilliance of the yellow color increases of course with surfactant concentration. In the presence of scattering colors, the absorption color is generally mixed with the scattering colors. Microscopic examination revealed that the 5.07% sample contains a large concentration of Mie particles, which do not produce scattering colors; hence the color is predominantly due to absorption. The same holds for the 0.263% sample in 1% brine, "first salt"; this sample was prepared by dissolving the salt first and then dispersing the surfactant. However, with the same composition but the inverse order of mixing, the particles fall in the Rayleigh or Rayleigh-Debye-Gans regime, at which blue scattering colors are observed. In this sample, the scattering colors mask to a large extent the absorption color.

DISCUSSION

A detailed guide for interpreting visual observations of surfactant dispersions has been set out. The guide is based on principles of light scattering and spectroturbidimetry and the perceptions of transparency and color; it can be also used for dispersions of other substances. The appearance of surfactant dispersions can be simulated by model dispersions of monodisperse polymer latex microspheres. Because observations can be subjective and the conditions of illumination can vary, comparison with model dispersions helps interpret observations objectively. Using dark background and high intensity illumination can of course improve the sensitivity of visual observations. This aspect remains to be systematically examined.

We believe that following the rules suggested here will help colloid scientists and engineers estimate quickly, simply, and fairly accurately the size range of dispersed particles and thereby to select rationally the research pathway for characterizing dispersions more definitively.

ACKNOWLEDGMENT

The National Science Foundation and the Department of Energy provided financial support for this work.

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[Received October 15, 1982]