Observations on shocked quartz in Cretaceous-Tertiary (K-T) boundary sediments compellingly tied to Chicxulub crater raise three problems. First, in North America shocked quartz occurs above the main K-T ejecta layer. Second, shocked quartz is more abundant west than east of Chicxulub. Third, shocked quartz reached distances requiring initial velocities up to 8 kilometers per second, corresponding to shock pressures that would produce melt, not the moderate-pressure shock lamellae observed. Shock devolatilization and the expansion of carbon dioxide and water from impacted wet carbonate, producing a warm, accelerating fireball after the initial hot fireball of silicate vapor, may explain all three problems.

In wells and outcrops of uninterrupted marine sedimentary rocks outside of North America, the K-T boundary is marked by a single 1- to 10-mm clay layer often containing anomalous iridium and altered impact spherules, widely interpreted as evidence for the impact of a large comet or asteroid (1) at the time of the K-T mass extinction of organisms 65 million years ago (Ma). A more complicated K-T boundary stratigraphy occurs in nonmarine sediments from New Mexico, United States, to Alberta, Canada, where the boundary interval begins with a bed of kaolinitic clay, which sometimes contains goyazite spherules and is typically about 1 cm thick, overlain by a layer 1 mm to a few millimeters thick that is rich in shocked mineral grains, particularly quartz (2, 3). The kaolinitic clay and goyazite spherules are probably alteration products of glassy ejecta (4-6) like that still preserved in a few sites around the Gulf of Mexico (5, 7, 8). Shocked quartz is formed under dynamic pressures of a few tens of gigapascals, depending on the target composition. An iridium anomaly is found in samples taken from the shocked quartz layer (9) and is attributed to the vaporization of the impacting meteorite because of pressures of many hundreds of gigapascals caused by a high-velocity impact. Some authors refer to the lower and upper layers, respectively, as the "melt-ejecta" and "fireball" layers (10).

Recognition of the Chicxulub structure (11) in the Yucatán subsurface as a giant impact crater (12) dating precisely from the K-T boundary at 65.0 Ma (13) and surrounded out to ~4000-km radius by proximal ejecta at the biostatigraphic K-T boundary (5, 7, 8) has strongly confirmed the general validity of the impact theory for the K-T mass extinction. Problems of detail remain, however, including three problems concerning the shocked quartz grains: (i) their vertical distribution in the double K-T layer of North America and their admixture with the iridium, (ii) the asymmetry of their geographic distribution about the Chicxulub crater, and (iii) their occurrence at great distances from the crater.

In North America, shocked quartz grains are virtually absent from the kaolinitic clay layer, except where apparently carried downward by biogenic disturbance. The clay layer and the quartz-bearing layer are sharply separated, and carbonized remnants of vegetation in the lower layer seem not to be present in the overlying quartz layer. This observation previously led to the notion that the layers were produced by two impact events at least one growing season apart; the vegetation traces in the lower layer were interpreted as roots of plants that grew before the overlying layer of ejecta was deposited (14). The lower layer was attributed to the Chicxulub impact and the upper layer to Manson crater in Iowa (14) until the following isotopic and age evidence eliminated Manson as a K-T candidate crater: (i) Sr, O, and Nd isotopic measurements showed the K-T impact glass to be indistinguishable from Chicxulub melt rocks but very different from Manson melt rocks (15). (ii) The Manson impact was dated as being earlier than the K-T boundary, at 73.8 ± 0.3 Ma (16). (iii) Shocked zircons from the shocked quartz layer have crystallization ages much younger than the basement rock at Manson but compatible with the granitic Pan African basement thought to characterize the Chicxulub tar-
adjacent moderately shocked granite to high velocity. This process provides a mechanism to address all three problems described.

The present study is relevant not only to the specific case of the K-T boundary but also to the understanding of impact processes in general. Large impact craters are common on rocky bodies in the solar system with the exception of Earth, where craters are relatively rare because they are erased by rapid geological processes. Comparison of studies of terrestrial craters (22) suggest that volatiles in the target body may significantly influence the impact processes and products. The Chicxulub crater is buried, so it is inaccessible but uncommonly well preserved. Study of this large, young terrestrial crater will help clarify the processes involved in comet and asteroid impact. Moreover, this was an unusual impact because of the combined carbonate and granite target lithologies, which would have generated large amounts of CO₂ and H₂O. Kieffer and Simonds (22) and O'Keefe and Ahrens (23) have given general consideration to the role of CO₂ and H₂O vapor in impact and the impact cratering process; we now apply these considerations to the specific case of the Chicxulub crater.

Global-Scale Ballistics of the Ejecta

We suggest that both the distribution of the shocked quartz and its occurrence in a separate layer can be explained by transport of the quartz grains on ballistic trajectories different from those of the glassy ejecta which altered to form the kaolinitic clay layer. We have calculated the reimpact loci of ballistic ejecta from Chicxulub as a function of the velocity and elevation angle of launch, taken around a 360° range of launch azimuths (24). Except when interacting with the atmosphere during launch and re-entry, ballistic ejecta particles follow elliptical orbits with one focus at Earth's center, when plotted in inertial coordinates, until they reimpact Earth's surface. We ignore atmospheric interactions during re-entry, considering them to have only a minor effect on the deposition point of sand-sized grains. However, settling times through the atmosphere may complicate our conclusions and need further consideration when more data on particle size and atmospheric conditions after impact are available. Interactions during launch are important and are discussed below, but the size of the expanding ball of gas around the impact site is small compared with long-range trajectories, so the particles can be treated as if launched into ballistic trajectories from the impact site once they leave the atmosphere.

Earth's rotation has two interesting effects on these orbits. The first effect is that the semimajor axis of the elliptical orbit depends only on the launch velocity in the inertial reference frame (25); to find this velocity, the eastward rotational velocity of Earth (0.463 km/s at the equator) is added to the target-frame launch velocity of eastbound particles, but subtracted from that of westbound particles. This has little effect on the semimajor axis of slow particles, but at launch velocities from about 8 or 9 km/s up to escape velocity (11.2 km/s), eastbound particles go higher and stay up longer than the corresponding westbound ones. The second effect is that, because Earth rotates beneath in-flight ejecta, the reimpact site is at the same latitude but displaced to the west, as compared with a nonrotating Earth. This effect is small for slow ejecta, but important for fast ejecta.

Because of these effects, there is a forbidden zone east of the impact site that cannot be reached by eastbound ejecta unless the launch velocity is high and the elevation angle low (Fig. 1). All of Europe and Africa is in the forbidden zone for ejecta launched at 70°, and all except the extreme western margin is forbidden at 60°. At 50°, the forbidden zone is reduced to a small area around India and eastern Africa. The known distribution of K-T shocked quartz would be well explained if most shocked quartz grains were launched from Chicxulub on trajectories steeper than about 65°.

Developing this concept, we propose that the double layer of ejecta in the western interior of North America reflects two different launch mechanisms during the cratering event. It has been proposed that the clay in the lower layer was formed by the alteration of glassy ejecta launched as part of the ejecta curtain (4–6). The ejecta curtain observed in hypervelocity impact experiments is an outward-expanding, downward-pointing cone inclined ~45° to the horizontal (26) and represents the coherent front of solid and melt ejecta particles on independent trajectories, launched at elevation angles ≤45°. Because a 45° elevation angle yields the longest ballistic range for a given launch velocity, this material will be the first to arrive at a given site (Fig. 2). For example, to reach the K-T site at Clear Creek, Colorado, ballistic ejecta launched from Chicxulub at an angle of 45° above the horizon requires an initial velocity of 4.4 km/s and has a travel time of 14 min. In contrast, if the shocked quartz at Clear Creek was reached at an elevation angle of 70°, as suggested by the global distribution, its initial velocity was 5.7 km/s and its travel time was 28 min. Ejecta-curtain particles launched at 30° to 45° have travel times to Clear Creek of about 10 to 15 min, whereas steeper ejecta particles, launched at

![Fig. 1. Reimpact patterns of ballistic ejecta launched at Chicxulub shown on a map of continental positions at K-T boundary time (the dashed line bounds pre-K-T Pacific plate that has not subsequently been subducted) (25). These patterns ignore atmospheric effects, which occur only at the times of launch and re-entry. For a launch angle of 70° above the horizon, thin lines show reimpact loci for launch velocities at 1-km/s increments. Heavy lines show the limit of the forbidden zone at 70° as well as for 60° and 50° launch angles; in the latter two cases reimpact loci are omitted to avoid clutter (36). Solid squares mark sites with coarse shocked quartz (grains >250 μm in diameter); circles mark sites with abundant fine shocked quartz; diamonds mark sites with rare, fine shocked quartz; and crosses mark sites where shocked quartz has been reported, but information is insufficient to determine its abundance. Schultz has suggested that the abundance of shocked quartz in the U.S. western interior K-T sites reflects a low-angle oblique impact toward the northwest (37). Alternatively, we propose that the asymmetrical distribution of shocked quartz, with heavy concentrations west of the impact site, can be explained if most grains were launched at an angle steeper than ~65°.](image-url)
We assume that a stony meteorite 10 km in diameter traveling at 24.6 km/s strikes a region with a 3-km-thick layer of wet carbonate overlying a granitic basement (33). During stage 2 and the early parts of stages 3 and 4, the shock Hugoniot and high-pressure parts of the release adiabats are relatively independent of rock type, and for these stages the shock equation-of-state properties used are those of diabase for the stony meteorite and those of granite for the target rock. The properties of volatile rocks become important later in the cratering event and are considered separately below. The meteorite is assumed to have a density of 3000 kg/m³, with a corresponding mass of 1.6 × 10¹⁵ kg and kinetic energy of 4.8 × 10²⁰ joules (114 × 10⁶ Mton).

On contact (stage 1), a shock wave is propagated into the target at nearly 20 km/s, shocking both the meteorite and the target up to a pressure of 660 GPa (Fig. 3A). For the first 0.5 s (stage 2), while the shock wave travels to the back of the meteorite, the meteorite penetrates through the carbonate and into the granite. The shock wave that is simultaneously traveling into the ground accelerates material downward or radially away from the meteorite, but not yet upward.

When the shock wave reflects from the back of the meteorite, it becomes a rarefaction wave that releases the shocked meteorite, and eventually the shocked target rock, back toward ambient pressure (stage 2b and Fig. 3, B and C). By the time the rarefaction reaches the meteorite-target interface, the meteorite has reached the end of its penetration path at 13 km. The meteorite and a closely adjacent mass of rock of roughly equivalent mass are vaporized and begin ascending in a hot fireball.

Although some energy is released along the whole penetration path, and although free-surface effects on the meteorite and target rock are important in detail (23, 32), to first order the process can be modeled by examining the decay of the peak-pressure isobars radially from a maximum value of 660 GPa centered in a mass of material at the depth of penetration (Fig. 3, B and C). Because the depth of penetration is only about one meteorite diameter, the shock waves penetrating downward have a different decay pattern than those moving toward, and reflecting from, the surface (22, 23, 30, 32). This causes radial differences in peak pressure which, combined with the different lithologies along different paths, influences the state of shocked material ejected.

In dry silicate rocks, the products of shock decompression vary with pressure in

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**Model of the Cratering Event**

A cratering model is required that explains the high velocities, near-vertical trajectories, and relatively cool temperatures needed for the shocked quartz to be carried far to the west and not annealed. To examine the cratering process, we used the semianalytic model of Kieffer and Simonds (22), in which the processes that occur during an impact event are subdivided into seven successive, sometimes overlapping, stages: stage 1, initial contact; stage 2, compression and release of the meteorite; stage 3, rarefaction and attenuation in the target; stage 4, excavation and flow within the crater; stage 5, ejecta launch and fallback; stage 6, mechanical modification; and stage 7, hydrothermal and chemical alteration.

In this article, we consider primarily stages 2 through 5. For each stage, the appropriate conservation laws and thermodynamic properties (or approximations) were solved to yield properties such as depth of penetration, duration of each stage, peak shock pressure in the meteorite and ground, and attenuation of peak pressure as a function of distance from the meteorite at its point of maximum penetration. Although this model is simplistic when compared with computer simulations such as those of O'Keefe and Ahrens (23) and Roddy et al. and Vickery and Melosh (30), it has the advantage of providing a relatively intuitive overview of the whole cratering process. The results (31) are in reasonable semiquantitative agreement with these earlier models and are in particularly good agreement with the model of Pope et al. (32) who did a similar calculation based on anhydrite thermodynamics in order to estimate climate effects. The sensitivity of the model to impact velocity and to meteorite and target composition is discussed in detail by Kieffer and Simonds (22).

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**Fig. 2.** Calculated history of ejecta arrival at Clear Creek, Colorado (37° 05′ 26″ N, 104° 31′ 33″ W), compared with the fine-scale stratigraphy of the K-T boundary at the Clear Creek North site of Izett (3), ignoring atmospheric effects during launch and re-entry. The boundary clay layer is made largely of kaolinitic clay, probably resulting from alteration of glassy ejecta (4-6). If launched in an ejecta curtain that is observed in experiments many orders of magnitude smaller, these particles would have had launch angles of 30° to 45° and would have reached this site in 10 to 15 min, with launch and reimpact velocities close to 4.5 km/s. The overlying layer is rich in shocked quartz. If these grains traveled on trajectories steeper than ~65°, as inferred from the geographic distribution of shocked quartz (Fig. 1), they would have had initial velocities >5.2 km/s and would have arrived >23 min after the impact. Launch velocities this high would imply energies sufficient to melt those obviously unmelted grains (21), so we infer that they were accelerated in an expanding "warm fireball" of CO₂ and H₂O vapor. Wispy carbonized remains within the boundary claystone, previously interpreted as the roots of plants that grew in an interval of ≥1 year between deposition of the two layers, may instead represent the stems of plants ignited by infrared heat from re-entry of the early ejecta and covered a few minutes later by the shocked quartz.
the following sequence: vaporized meteorite and vaporized rock (shocked to pressures over 100 GPa), melted rock (shocked to pressures >50 GPa roughly), highly and moderately shocked rock (including shocked quartz grains and shocked feldspars at pressures of a few tens of gigapascals), weakly shocked, and then fractured rock. These are the products that we would expect shocked quartz to be produced under the meteorite site at depth. Thus, we expect shocked quartz to be produced under the meteorite site at depth.

A hot fireball is formed from vaporized material surrounding the penetration cavity (Fig. 3, B and C). The rise of this vapor from the impact site may be coupled with other atmospheric phenomena such as atmospheric preheating during entry of the meteorite and explosions if the meteorite had partly disintegrated within the atmosphere (34)

Complicated shock waves travel in the air, both from the initial meteorite entry and from the rising and decompressing fireball. This hot vaporized material is rich in meteoritic components and in vaporized components from near the penetration cavity, carbonate and silicate in this case.

The strongly, moderately, and some of the weakly shocked material surrounding the impact site and lining the walls of the expanding transient cavity is turned upward and outward by rarefaction waves. This flow develops into the ejecta curtain formed by the coherent front of melt and solid ejecta launched at an angle of ≤45° and at velocities of a few kilometers per second. It would be expected that the shocked quartz produced deep under the impact point proximal to the melt zone would largely be entrained in the ejecta curtain (22). However, if 4.5 km/s is the maximum launch velocity that will not anneal or melt shock features (21), then shocked grains will travel no farther than the Gulf Coast of the United States (24); this agrees with the presence of rare shocked quartz in ejecta-curtain (lower layer) deposits in the Gulf of Mexico K-T sections (8) and the absence of shocked quartz in the lower K-T layer in the western United States (3-5) (Fig. 1).

In the granite above the depth of penetration we would expect the same sequence of shocked products as produced below the meteorite. The relative abundances will be different than below the meteorite because they are influenced not only by radial pressure decay but by free-surface and entry path effects. We estimate that at a radial distance of ~10 km from the center of impact, shock pressures are a few tens of gigapascals, and lamellae and other deformation features should be produced in the granite.

The wet carbonate cover, however, has a vastly different behavior in these pressure ranges. Wet carbonate can produce CO₂ and H₂O vapor at relatively low pressure; devolatilization of incorporated anhydrite would also contribute volatiles over approximately the same pressure range. Although data are sparse and somewhat inconsistent, in general it is agreed that carbonates partially break down into CaO and CO₂ on decompression from ~45 GPa and completely break down if shocked to over ~70 GPa. The pressure range for anhydrite breakdown is similar, although the degree of equilibrium attained in any of these devolatilization reactions is a subject of much controversy. In our simple model, 70 GPa is reached at a radius of ~11 km (surface) and 45 GPa at about 12 km. Water in pores and cracks will vaporize if shocked to over 10 GPa, reached at a surface radius of 18 km in this model.

Material in the carbonate layer out to a radius of at least 18 km will partially or even totally vaporize, releasing a mixture of steam, CO₂, oxides, and fragments of the carbonate. This is a very large amount of vapor. If we consider only an annulus of carbonate between 11- and 18-km radius, shocked to between 70 and 10 GPa, the volume of material is 2000 km³. At a density of 2500 kg/m³ (purposely reduced from the density used for average shock wave properties of the target to allow for some porosity and water content), the mass would be 5 × 10¹⁵ kg, approximately three times the mass of the impacting meteorite. A typical energy for vaporizing this material is about 10¹⁴ ergs/kg. If only 10% of the material vaporized, this would require input of 3 × 10¹³ ergs, or about 10⁵ Mton. This energy would be deposited in the vapor on a time scale of a few seconds.

We suggest that the CO₂ and H₂O vapor from this devolatilized carbonate zone between ~10 and 20 km (rounded off) ascended as a "warm fireball" which dragged...
Prediction of a Third Layer

The K-T impact bed in the western United States contains two clearly recognizable layers. We interpret the lower layer as representing the ejecta curtain and the upper layer as derived from the warm fireball. The iridium anomaly is found in samples taken from the upper layer. The carrier for iridium has never been recognized in any K-T sites, and it probably occurs in extremely fine particles. Iridium and quartz come from different sources: vaporized meteorite and unmetelated basement, respectively. The iridium is likely to have been deposited as a separate veneer on the top of this upper layer because of the slow settling of fine particles. Iridium does occur in the finest material at the top of the marine K-T boundary beds in the deep Gulf of Mexico (8). We therefore predict (Fig. 2) that even higher resolution iridium stratigraphy should reveal a triple boundary layer at sites in the western United States, with the three layers related to three distinct mechanisms for launching ejecta during the impact event: (i) An extremely hot fireball consisting of vaporized meteorite and target-rock carbonate and silicate is launched first, but because of the fine grain size of the material it carries, this is the last portion to settle. (ii) A ~45° ejecta curtain carries melted and shocked solid rock fragments that are emplaced first because of their lower, more direct trajectories. (iii) A quite distinct warm fireball of CO₂ and steam accelerates moderately shocked granite fragments into ballistic trajectories steeper than about 65°, and they arrive after the ejecta curtain material but before the hot-fireball iridium.

Conclusion and Applicability

In order to address the processes that occur during planetary-scale impacts, this study has involved field, laboratory, and theoretical aspects. Because of the sheer scale of the process, no single technique is likely to be sufficient. As sophisticated as numerical modeling of the theoretical concepts has become, the complexities of the material properties of geologic, planetary, and meteoritic compositions and processes cannot be addressed. Laboratory experiments are inherently limited in scale and duration, but they provide valuable insights about processes, rates, and material properties. Field observations are limited by exposure and interpretation, but they are global in scale. In this study, we have proposed a model based on all three techniques of geologic analysis and have proposed some tests to guide further work. We have proposed that a thin veneer (3 km) of volatile sediments strongly influenced global ejecta distribution. If true, then Chicxulub will provide a valuable analog for impact studies on both dry planets (moon, Mercury) and volatile-containing planets (Mars, Venus).

REFERENCES AND NOTES


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21. Deformation features are directly correlated with peak shock pressure. Numerous studies show that moderate shock features (reduced refractive index, lamellae, microfractures) between 20 and 40 GPa (depending on the rock type), and shock-fused quartz at pressures above 50 GPa. In turn, peak shock pressure is directly related to the particle velocity attained behind the shock. To a very good approximation in dry rocks, the velocity is doubled by the passing rarefaction [R. G. McQueen, S. P. Marsh, J. N. Fritz, J. Geophys. Res. 72, 4969 (1967)]. For a peak shock pressure of 20 GPa, the measured shock velocities in 12 representative rocks are 0.8 to 1.4 km/s. The rarefaction velocities are then in the range of 1.6 to 2.8 km/s. Ahrens and Rosenberg [In Shock Metamorphism of Natural Minerals, B. French and N. Short, Eds. (Mono, Baltimore, MD, 1968), p. 59] extended the range of pressures to 45 GPa and measured all rarefaction (free surface) velocities to be less than 4.5 km/s. We therefore take 4.5 km/s as an upper limit on the velocity that could be attained by moderately shocked quartz grains launched by a simple cratering event. At higher pressures, higher rarefaction velocities are obtained, but the features of moderately shocked quartz are not preserved because the quartz is annealed or fused. Target rock texture (porosity in this case) and wetness also affect shock metamorphic features and rarefaction velocities [S. W. Kieffer, J. Geophys. Res. 76, 5449 (1971)]. A significant effect for this discussion is that porosity and water both increase the possible rarefaction velocities. For example, dry soil (porous quartz soil) shocked to 30 GPa releases the velocity of 5.7 km/s, higher than that measured for single crystal or nonporous polycrystalline quartz. Wet soil shocked to the same pressure releases with a particle velocity of ~7.3 km/s [G. D. Anderson et al., Technical Report APWP-TR-65-146 (SRI International, Minitc Park, CA, 1965)]. Thus, an impact into porous, water-saturated carbonates will produce products with significantly higher velocities than a similar impact into a dry, nonporous silicate target.


24. W. Alvarez, in (19). The necessary equations were modified from those given by A. Dobrovolskis [Icarus 47, 2003 (1981)]. His dimensionless parameters were converted to Earth's case as follows: 1 time unit = 6.96 x 10^19 s, 1 length unit = 6371 km, and 1 mass unit = 5,973 x 10^27 g. Time-of-flight calculations followed those described by A. D. Dubylago [The Determination of Orbits (MacMillan, New York, 1961)].

25. The semimajor axis, a = (√2 + v) in dimensionless units, where v is the launch velocity.


31. The "rocas volcánicas" mentioned on p. 277 are probably the impact melt rocks of the Chicxulub crater, not basalt rock.


34. At velocities greater than 10 km/s, ejecta can travel further west, but not farther east, so these are firm limits on the west edge of the forbidden zone for each elevation angle. Cusps in the boundaries of the forbidden zones are an artifact produced by joining segments of impact foci lines at 1-km increments.


36. We thank J. Bostwick and F. T. Kyte for discussion and for a preprint of their work on the K-T boundary of the Pacific plate and D. Rowley for plate-rotation parameters. Comments by R. Jenknez and C. Koeberl on an earlier version of this manuscript are greatly appreciated. Supported by the National Aeronautics and Space Administration (NASA) grant NAGW-3090, and NSF grant EAR-81-05297 to W.E.A., NASA grant NAGW-1740 to G.W.K., and University of California Berkeley Espeo A. Larsen Jr. Research Fund.

### Resonance Light Scattering: A New Technique for Studying Chromophore Aggregation

**Robert P. Pasternack and Peter J. Collings**

Light scattering experiments are usually performed at wavelengths away from absorption bands, but for species that aggregate, enhancements in light scattering of several orders of magnitude can be observed at wavelengths characteristic of these species. Resonance light scattering is shown to be a sensitive and selective method for studying electronically coupled chromophore arrays. The approach is illustrated with several examples drawn from porphyrin and chlorin chemistry. The physical principles underlying resonance light scattering are discussed, and the advantages and limitations of the technique are reviewed.

We have recently reported (1) on a new resonance technique called resonance light scattering (RLS) that is both extremely sensitive and selective in probing chromophore aggregation in a number of different systems. The theory behind this technique is not new, and in fact RLS has been tried in the past for purposes other than studying aggregation. In those cases, the technique was only marginally successful. However, we have found that in aggregation experiments, RLS not only meets sensitivity and selectivity criteria but offers the additional benefits of simplicity and versatility. In this article, we describe the basic physics behind RLS, survey some ongoing research on its refinements and application to different systems, and discuss a number of areas in which RLS may make important contributions in the near future.

### Experimental Approaches to Studying Aggregation

The recent flurry of research activity on supramolecular assemblies and their application in the construction of nanodevices has encouraged the development of experimental techniques capable of detecting and characterizing these assemblies. Understanding the chemical, biological, and pharmacological activity of a complex system requires knowledge of the state of molecular aggregation of the system’s components. Research issues that involve relations between the properties of complex systems and the formation of large aggregates include (i) the organization of chlorophyll and other pigments in chlorosomes, in which a particular molecular assembly is required for efficient photosynthesis (2); (ii) the relation of photosensitization efficiency to the extent of aggregation of the active component at cancer cells, which must be resolved to enable rational design of alternative reagents in photodynamic cancer therapy (3); and (iii) the state of aggregation of lipids and drugs in liposomes, which has been shown in certain cases to be a crucial factor in their effectiveness in treating disease (4). Although light scattering experiments are frequently used to study such problems, in these three examples conventional light scattering would likely not yield useful data because of the background signals provided by the medium; not only the existence but the identity of the scatterer must be determined.

Even though light scattering experiments...