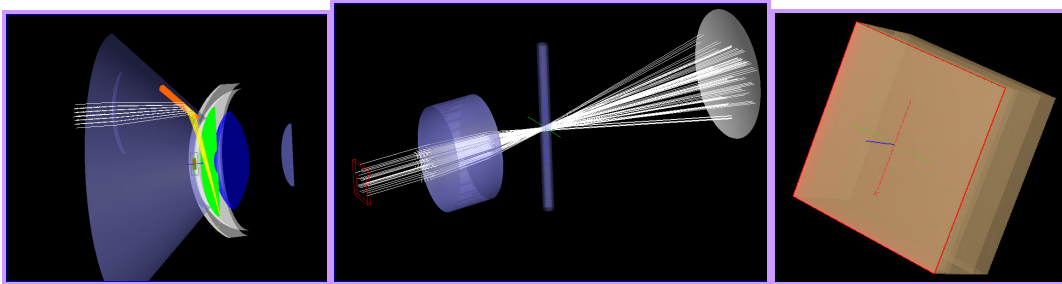


From non-invasive procedures to ultra-sensitive diagnostic instrumentation, photonic devices play an indispensable role in today's bio-medical industry. For the last quarter century, timely design and delivery to market of these new technologies has been possible only with the aid of sophisticated software tools and experienced optical engineers. Photon Engineering firmly believes that its optical engineering product **FRED** can help accelerate the pace of innovation in the biomedical community by enabling its members to participate more fully in the process. **FRED** combines a GUI interface, where geometry creation and visualization are intuitive, with a powerful computational engine capable of satisfying the most demanding requirements. The relevance of **FRED** to the bio-medical industry can best be expressed by presenting several familiar yet innovative applications such as a gonioscope, laser-induced fluorescence in a capillary, and a human skin model.



Biomedical Optics Example 1: Gonioscopy Lens

The ability to monitor the iridocorneal angle is a critical factor in the diagnosis and treatment of glaucoma. To measure this angle between the iris and the internal surface of the cornea, a gonioscope must illuminate these surfaces through the entrance of the eye and efficiently collect the returning light.

An essential element in simulating the operation of a gonioscope is an accurate model of the human eye. Figure 1 below shows a view of the anterior portion of the human eye constructed in **FRED**. This particular eye model is based upon a reference model of the eye attributed to Smith & Atchison and Schwiergling². The material properties for this eye model have been obtained from Tuchin³. All essential elements of the eye are included in this model; the front and rear surfaces of the cornea, the iris, the eye lens and aqueous humor. Several complete eye models can be found in the Samples folder of the **FRED** installation directory.

Should elements of the eye model require alteration, the complete collection of parameters used

in their definition are available from multi-tab dialog boxes such as the one shown in Figure 2.

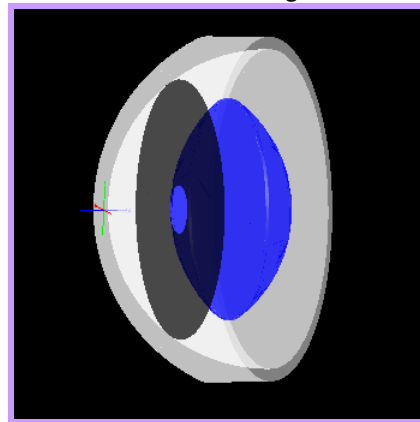


Figure 1. **FRED** model: anterior portion of the human eye.

The user has direct access to curvatures, apertures, trimming, positioning, materials, scatter, coatings, and visualization properties in a central location in the **FRED** interface.

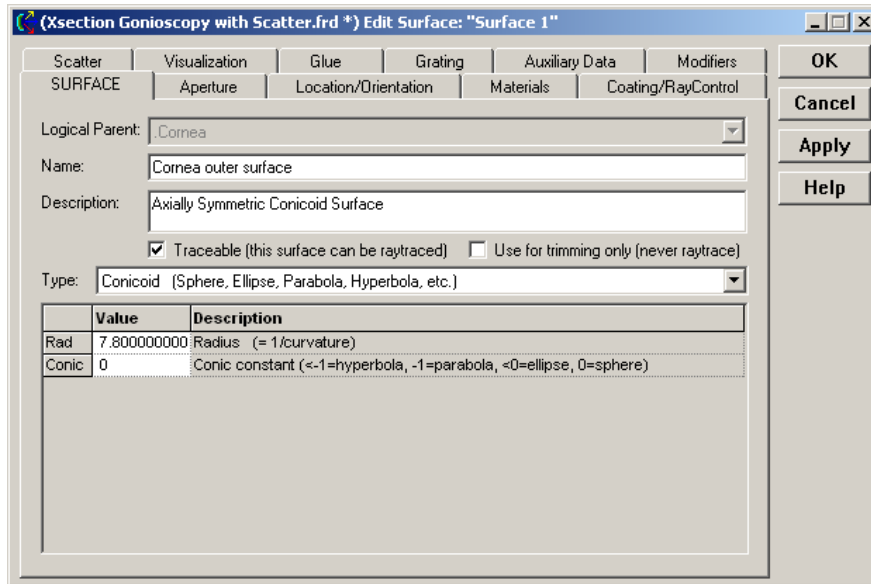


Figure 2. FRED surface properties dialog box.

With the eye model readily available, the next step in building this simulation will incorporate a gonioscopy lens. FRED offers trouble-free import of lenses designed in CodeV, Zemax or Oslo. Positioning of the goniolens with respect to the cornea a simple operation in FRED. FRED maintains a local coordinate system for each surface. Objects, as they are added to a model, can be located relative to other objects. Figure 3 below shows the placement of the gonioscopy lens being set with respect to the cornea outer surface.

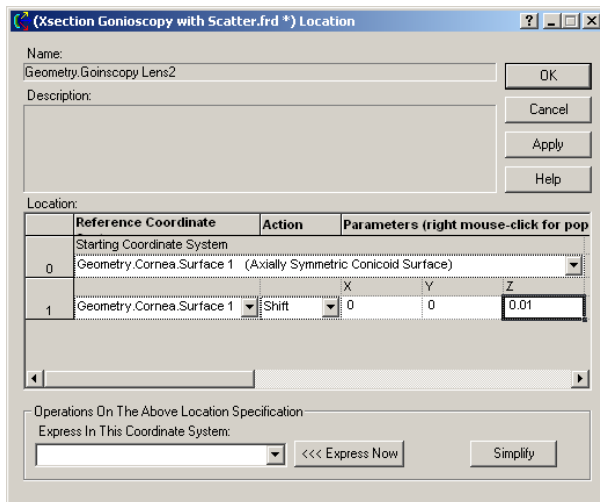


Figure 3. Locate an object in any coordinate system.

In practice, this lens is coupled to the cornea by introducing an index matching fluid between these surfaces. FRED has a unique “gluing” feature which allows for easy insertion of this matching layer. Contacting these surfaces is as simple as entering the edit mode for the rear surface of the goniolens, opening the Glue tab, selecting the cornea anterior surface as the surface to be glued to, and finally selecting the material to use for gluing. This operation is shown in Figure 4 below. Figure 5 shows the complete geometric model.

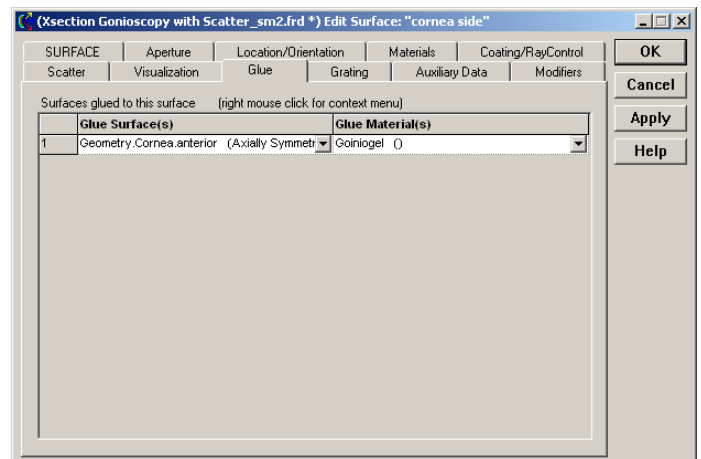


Figure 4. “Gluing” the goniolens to the cornea.

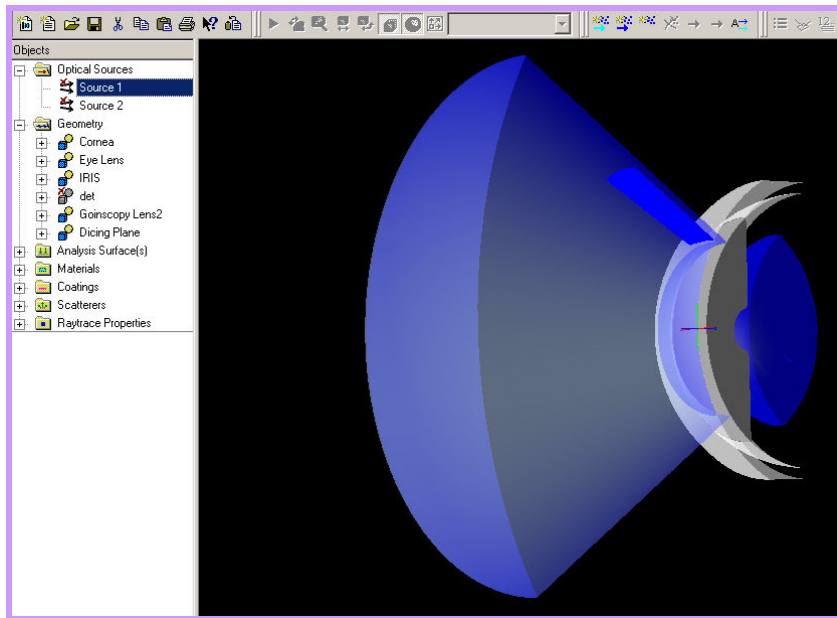


Figure 5. Cut-away view of **FRED** goniolens and eye model.

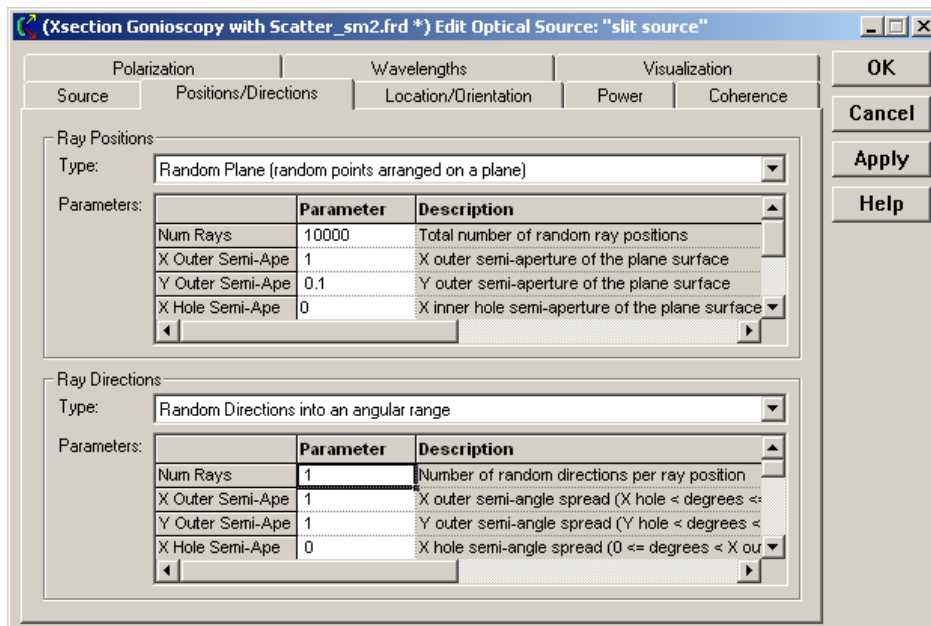


Figure 6. Positions/Directions Tab for Source dialog box.

With the geometry for the model now complete, the next step in preparing this simulation is to create the light source which will illuminate the anterior chamber of the eye (between the inside of the cornea and the iris). Standard gonioscopy procedures indicate the need for a slit source to produce optimum illumination. Shown in Figure 6 is the **FRED** Source dialog box used to create rays for tracing. The Positions/Directions tab allows the user to set the number of rays, source dimensions and angular properties.

For more in-depth analysis, the user may require the source have a particular spectral content or be apodized in angle or position. These along with many other aspects of a source definition are found amongst the various tabs in the Source dialog box. The user could choose the standard CDF wavelengths as shown in Figure 7 or digitize the source spectra from a graphic such as a spectral curve as shown below in Figure 8. Note that in both cases, **FRED** can color rays according to their individual wavelengths for easier visualization.

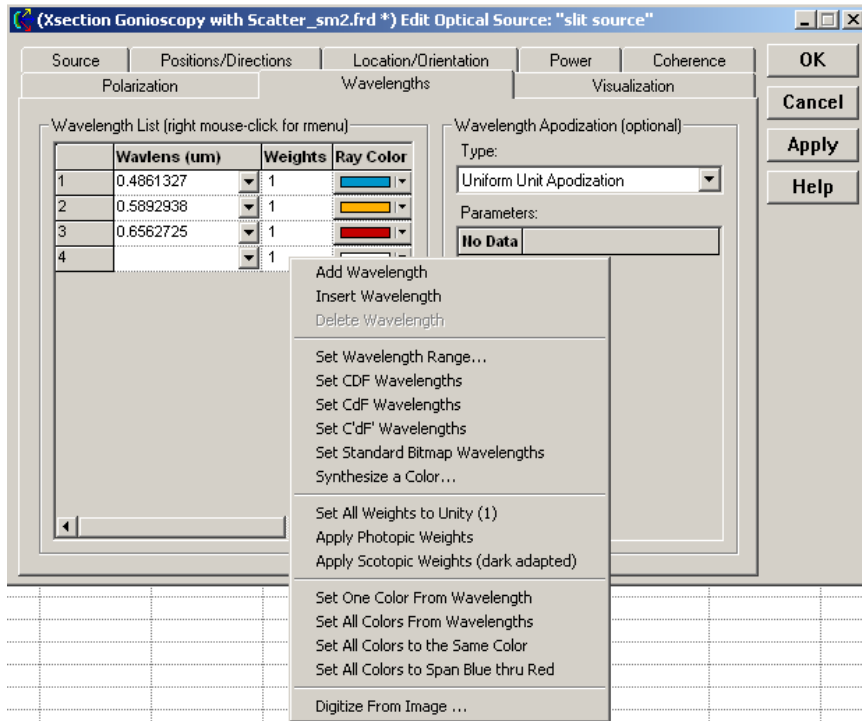


Figure 7. Setting source spectra in **FRED**.

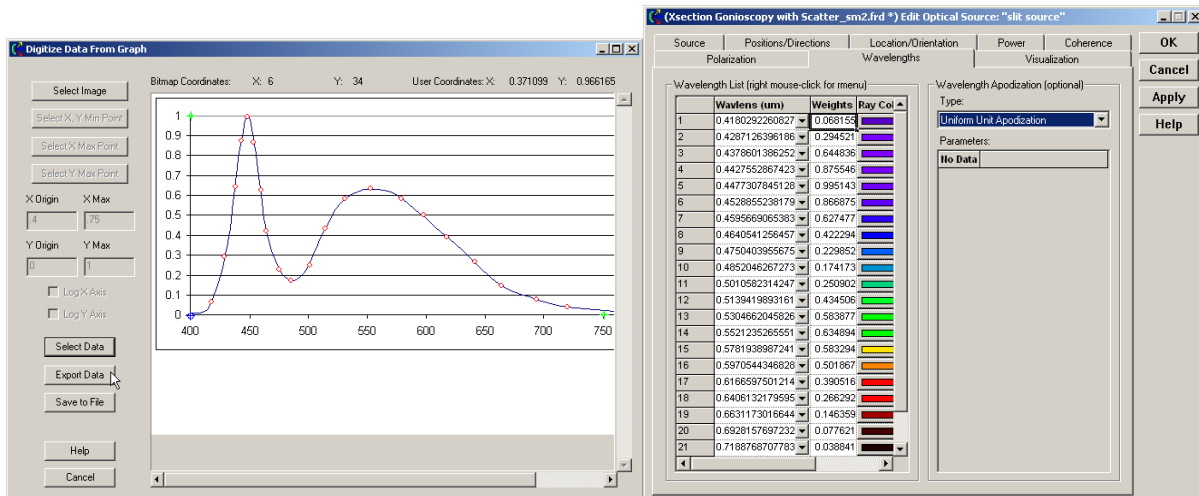


Figure 8. Create a **FRED** source by digitizing a graphic containing spectral data.

Adding an apodization to the source definition is also a straightforward operation. The Power tab of the **FRED** Source dialog offers several pre-defined apodizations along with the option for customized profiles. Shown in Figure 9 is an example of Gaussian spatial apodization typical of a laser diode or LED:

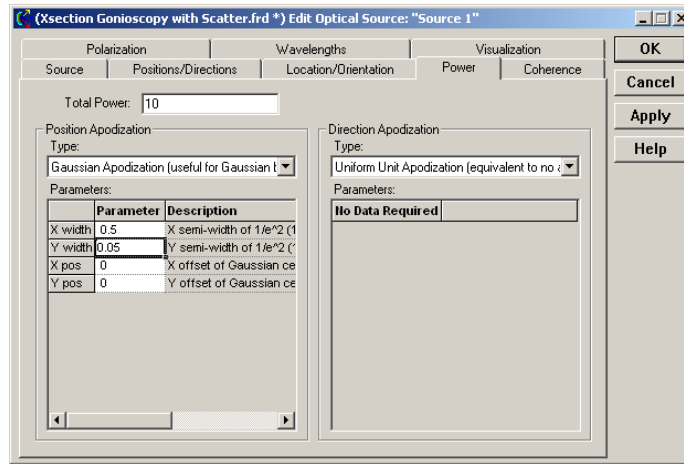


Figure 9. Gaussian spatial apodization of a **FRED** source.

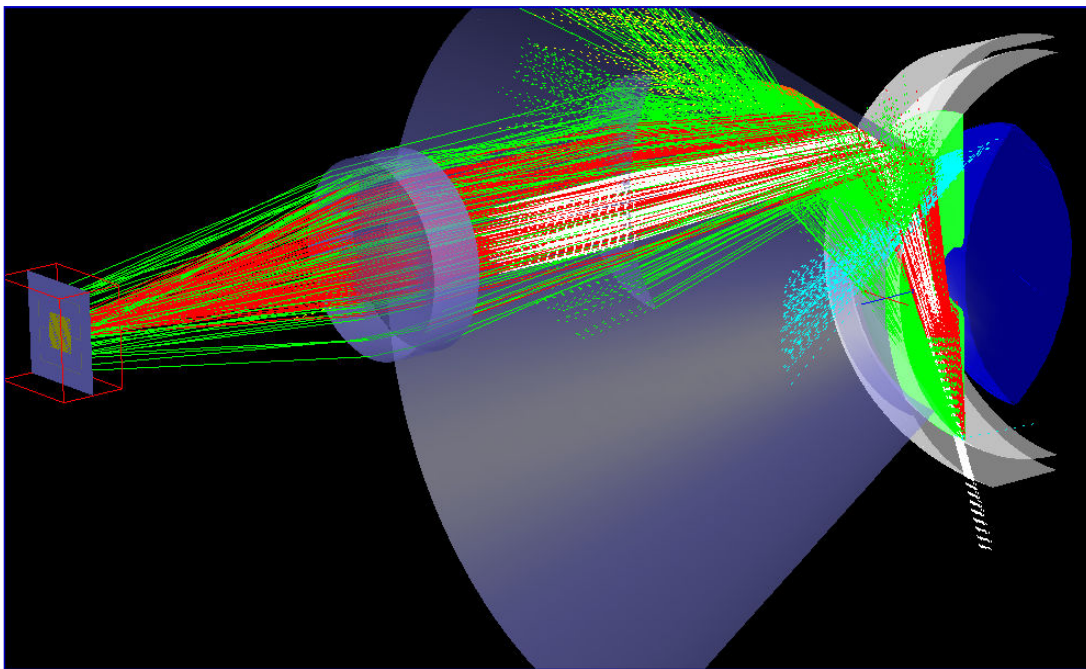


Figure 10. Goniolens model with raytrace paths. Ray colors indicate specific surface intersections.

After position the source to achieve the optimal illumination, a supplemental optic may be desirable to image light exiting the goniolens. **FRED** offers the convenience of choosing from hundreds of stock lenses in seven popular vendor catalogs. The completed and raytraced model is shown in Figure 10.

In this rendering, rays are not colored according to wavelength. **FRED** has the ability to assign a chosen color to a ray that strikes a given surface under any of four distinct conditions: reflection, transmission, scattering or diffraction. In Figure 11, rays scattering from the cornea rear surface are changed to **green** and those scattering from the iris to **red**.

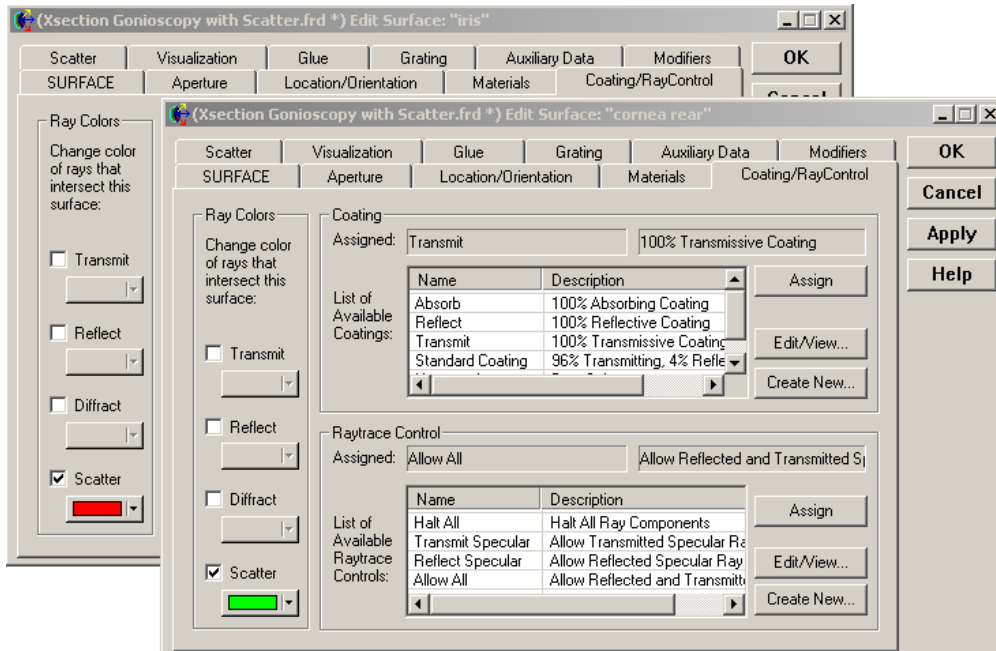


Figure 11. Setting ray color based upon surface and intersection type.

As an example of analyses available in **FRED**, spot diagrams at the lens focus are shown for rays scattered from the iris and inside the cornea in Figure 12. The upper plot and lower plots contrast the

difference between a flat and curved irises as shown on the right. As expected we can see the image shearing with the smaller or closed angle in the lower chart.

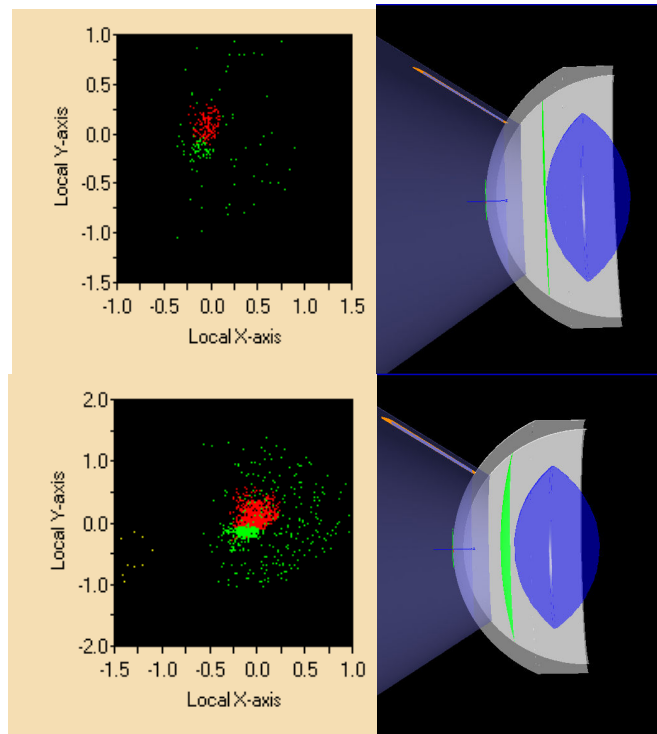


Figure 12. Spot diagrams using planar and curved irises.

1. *The Eye and Visual Optical Instruments*, G. Smith & D. Atchison, Cambridge University Press, 1997
2. *Visual Optics Course Notes*, Jim Schwiergling, Optical Sciences Center, University of Arizona, 2000.
3. *Tissue Optics; Light Scattering Methods and Instruments for Medical Diagnostics*, Valery Tuchin, SPIE Press, 2000.

Biomedical Optics Example 2: Laser Induced Fluorescence – Capillary Electrophoresis

Capillary electrophoresis is a powerful technique used in genetic analysis and protein characterization. A collimated laser beam is focused into a glass capillary column where material to be analyzed flows under the influence of an electric potential. When specific particles or compounds pass through the illuminated volume, they fluoresce with a characteristic spectra. This example illustrates how **FRED** implements the phenomena of fluorescence through a specialized feature in its scattering library.

In Figure 13, a collimated rayset representing an ultraviolet laser beam is focused by an objective lens into a glass capillary filled with fluid. The mirror at top right is used to enlarge the illuminated volume by reflecting unused laser light back into the capillary on a slightly different but overlapping trajectory. This larger illumination volume serves to increase the fluorescent signal being collected. Optics oriented perpendicular to the laser illumination path collect the fluorescent light for analysis.

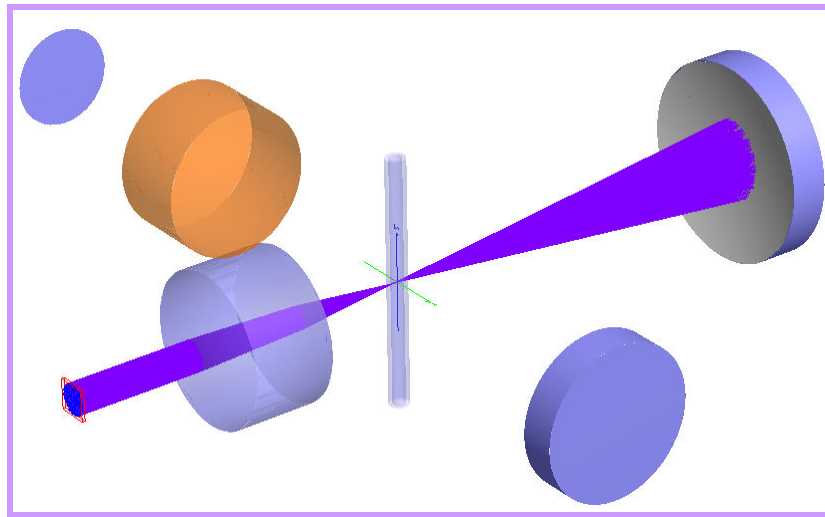


Figure 13. Capillary Electrophoresis layout with collection optics.

A close-up view of a particle flowing through the laser illumination path in the capillary can be seen in Figure 14. The key element of this simulation will be an ability in **FRED** to assign fluorescent properties to such particles. The physical process of fluorescence involves conversion of light at one wavelength to that of a longer wavelength. An intrinsic feature of **FRED** essential to modeling fluorescence is that wavelengths

are assigned to rays on an individual basis. When coupled with the flexibility of **FRED**'s scripted scatter model feature, the path to a practical simulation of fluorescence becomes evident. Given a particular emission spectra, a scripted scatter model can be constructed that reassigns ray wavelengths by interpreting the emission curve in terms of probability.

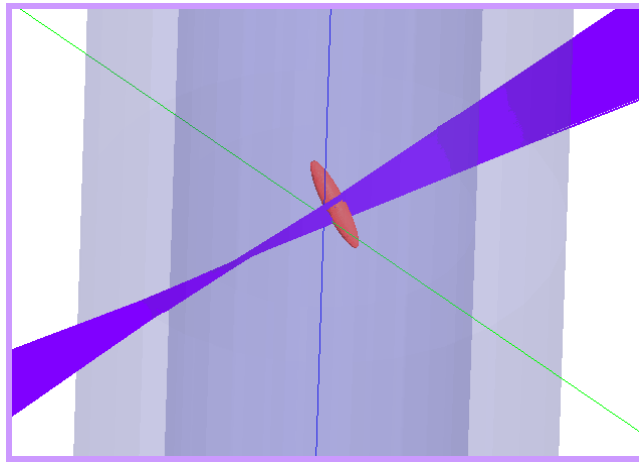


Figure 14. Close-up view of particle passing through illumination path.

For the purposes of this example, particles in this simulation will be given the fluorescent properties of Rhodamine 6G, a widely used organic dye. The emission spectra^{4,5} of R6G is shown in Figure 15. The resident digitizer in **FRED** lends itself quite nicely to

generating a dataset from this graphic. That dataset becomes a part of a compiled Enable Basic routine resident in a Scripted Scatter Model. As a result, this fluorescence routine has no adverse impact on simulation time.

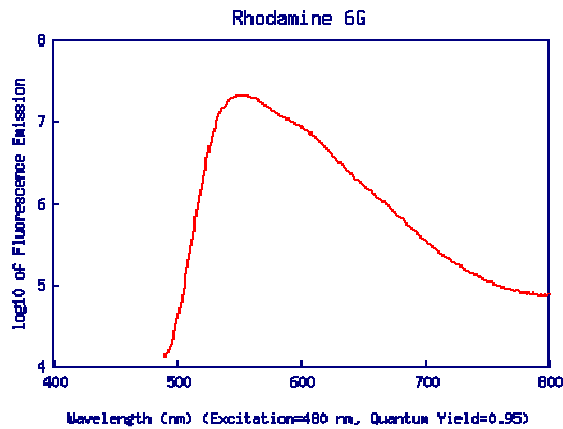


Figure 15. Emission spectra of Rhodamine 6G dye.

An essential ingredient in any simulation involving scatter is raytrace efficiency. Since valuable resources would be wasted tracing rays into the entire hemisphere, the ability to direct the fluorescence only towards the collection mirror and lens can translate into significant time savings. The Importance Sampling feature in **FRED** serves precisely this function. The dialog box shown in Figure 16 illustrates how easily this feature is implemented. Importance Sampling is implemented from the Scatter tab in the “Fluorescing Particle” Edit/View dialog as shown on the left in Figure 16. The Importance Sampling Specification on the right specifies that scattering occurs “toward an

entity” which is selected from a dropdown menu containing all **FRED** entities.

A graphical representation of the complete simulation is shown below in Figure 17. Purple represents the illuminating path while the orange maps the fluorescence. While the ray colors shown here are approximate, it is possible with the Color Image feature in **FRED** to display the source and fluorescence colors in standard RGB representation. Figure 18 shows RGB and chromaticity charts for the laser source (top) and the fluorescence captured by the collection optics (bottom).

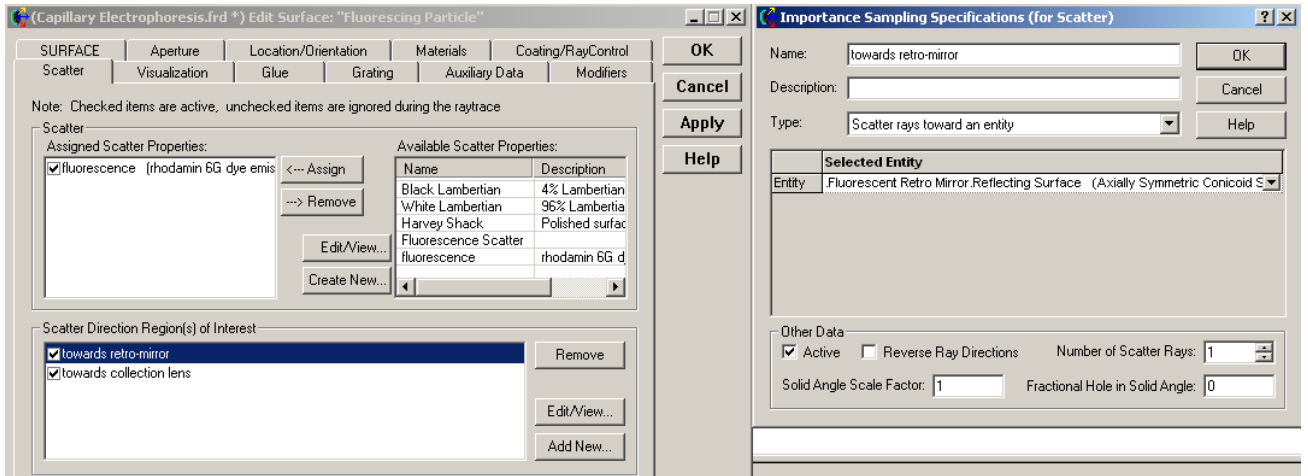


Figure 16. Importance Sampling: scattering toward an entity.

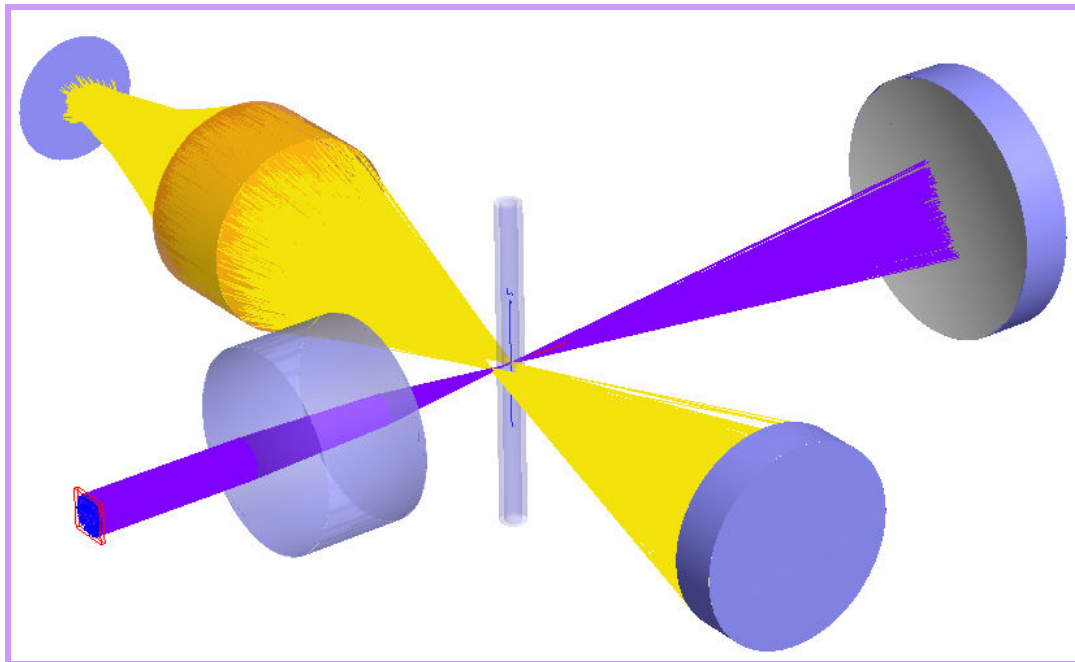


Figure 17. Capillary Electrophoresis simulation with illumination and fluorescence paths.

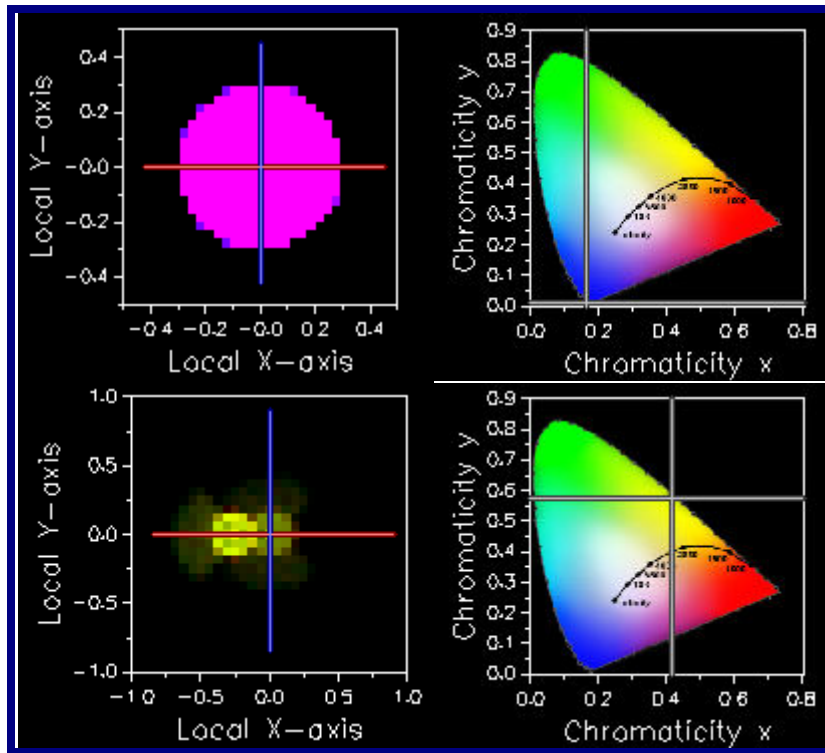


Figure 18. Color Image (RGB) representation of source and fluorescence.

4. Graphic obtained from <http://omlc.ogi.edu/>

5. R. F. Kubin and A. N. Fletcher, "Fluorescence quantum yields of some rhodamine dyes.," *J. Luminescence*, 27, 455-462, 1982

Biomedical Optics Example 3: Human Skin Model

Human skin models are valuable aids in the design of non-invasive diagnostic devices such as the oximeter as well as in the development of modern dermatological instruments. With the release of version 6.20, **FRED** now offers the Henyey-Greenstein volume scatter model recognized by the biomedical community as being representative of scattering in human tissue. There are numerous sources for the parameters associated with this model, namely an

anisotropy factor g and the scattering and absorption coefficients μ_s and μ_a . In **FRED**, this volume scatter model is applied through a material definition shown in the dialog boxes shown here in Figure 19. Once such materials are defined, they can be assigned to various interfaces in a geometric model by the drag&drop method.

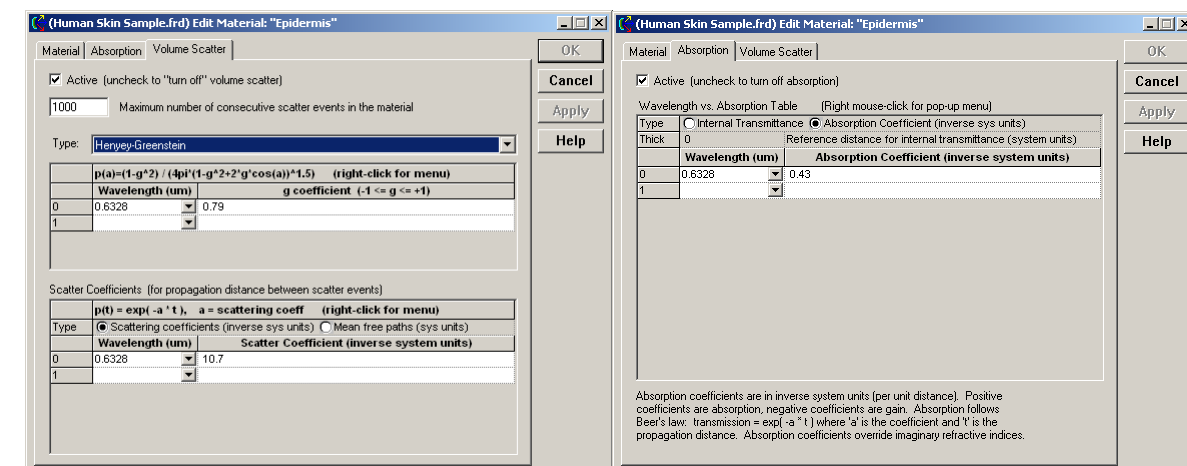


Figure 19. Defining the Henyey-Greenstein volume scatter model.

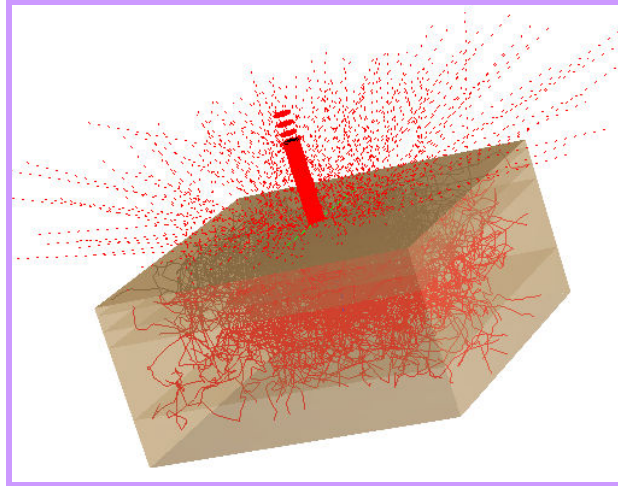


Figure 20. Sample raytrace of human skin model.

FRED features pertinent to biomedical applications:

- Surface, Volume and user-defined Light Sources
- Lens, Mirrors, Prisms and Materials catalogs
- Surface Scatter
- Henyey-Greenstein Volume Scatter model
- Fluorescence simulation
- Importance Sampling
- Multi-threaded non-Sequential Raytracing
- Analysis Tools
- Graphic Visualization

As demonstrated in these biomedical optics examples, **FRED** has the critical and visually dynamic capabilities for modeling, analysis, and graphical display capability. If you have any questions regarding **FRED**'s capability to model and analyze your biomedical optical system, simply contact us by phone or email.

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