

angle! This feature is the *primary rainbow* whose existence was previously explained in section 4.3.1 using the ray tracing method (Fig. 4.8) and assuming a single internal reflection of the ray. The slightly weaker peak at $\Theta = 130^\circ$, just to the left of the primary rainbow, is the secondary rainbow, which is associated with rays undergoing two internal reflections in the sphere.

In summary, the Mie solution, which is based on an infinite series solution of the EM wave equation with suitable boundary conditions, yields results which basically converge to the geometric optics results, once we let x get large enough. In fact, for $x > 2000$ or so, we have crossed out of the range of x for which Mie theory is traditionally applied (see Fig. 12.1). Even for very large x , however, there are aspects of scattering by particles that geometric optics alone can never explain, such as the forward diffraction peak as well as the intensified scattering near 180° known as the *glory*.

The polar plots in Fig. 12.8 and Fig. 12.9 provide an alternative way of visualizing the evolution of the phase function with increasing x . In the first of these, the amplitude of the phase function is proportional to the distance along a particular radial at angle Θ , with $\Theta = 0$ pointing horizontally to the right. For $x = 0.1$ we again have the symmetric Rayleigh phase function; you'll probably recognize the shape from Figs. 12.2 and Figs. 12.3. For even modest increases in x , the asymmetry quickly becomes very pronounced. By the time we reach $x = 10$, the forward scattering lobe is already so intense that it no longer fits on the page!

For larger x , we can tame the extreme features of the phase function by making the radial amplitude proportional to the *logarithm* of $p(\cos \Theta)$ (Fig. 12.9). Among other things, these plots allow us to clearly see, for the first time, what's happening at $\Theta = 0^\circ$ and $\Theta = 180^\circ$. There are a few features that deserve special mention, because they are associated with commonly observed optical phenomena:

Forward Diffraction Peak

We have already mentioned the strong forward scattering that occurs in connection with larger particles, spherical or not. This phenomenon is readily observable in daily life. It is much harder to

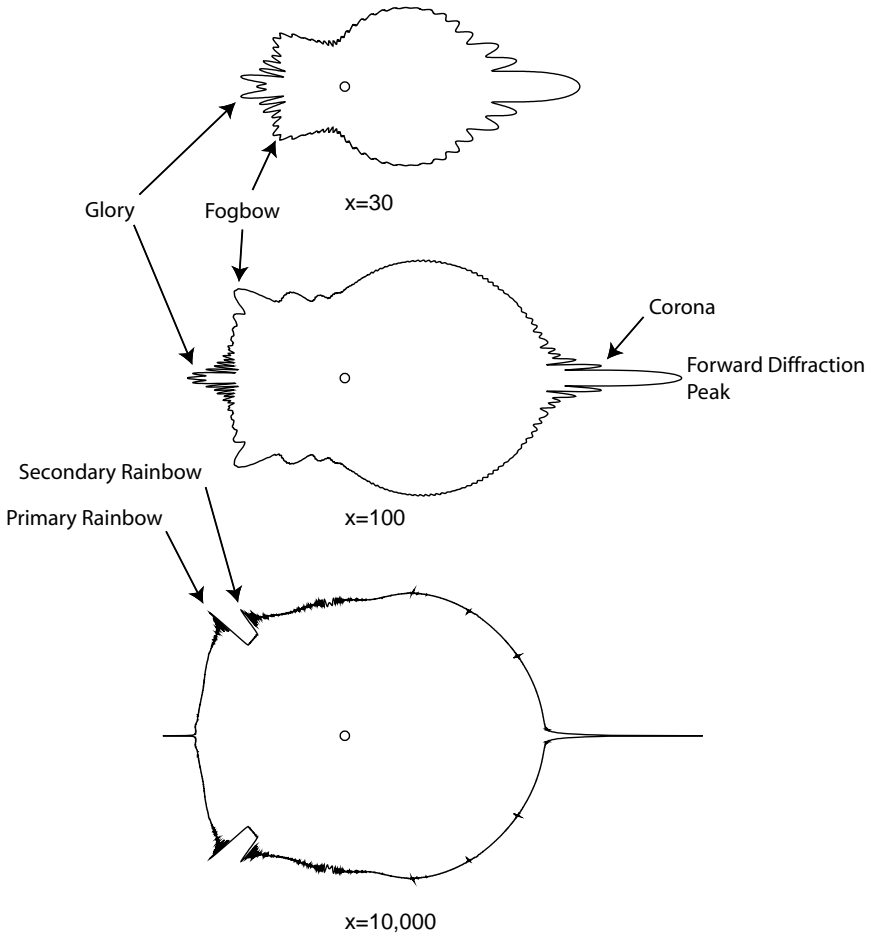


Fig. 12.9: Similar to Fig. 12.8, but plotted as $\log[p(\Theta)]$ so as to better accommodate the extreme variations in the amplitude of the phase function for large x . Commonly observed optical features associated with the phase function are indicated. Note the δ -function-like characteristic of the forward and backward peaks for the largest values of x .

see through the glare of a dirty windshield when driving toward the sun than away. Dust particles settling through a shaft of sunlight in a room are easiest to spot when looking generally toward the source of the light. The rays of light from the setting sun emerging from a break in the clouds (so-called *crepuscular rays*) are most evident when viewed in the general direction of the sun.

Fig. 12.9 makes much clearer the profound narrowing of the diffraction peak with increasing x . For $x = 10,000$, the peak is so narrow that the scattered radiation it represents might as well be considered as never having been scattered at all. In the geometric optics approximation, this feature doesn't even exist! In fact, while Mie theory predicts $Q_e \approx 2$ in the limit of large x , geometric optics always predicts $Q_e = 1$. The forward diffraction peak is largely responsible for the discrepancy.

Corona

For intermediate values of the size parameter x , the forward diffraction peak is accompanied by number of weaker *sidelobes*. If you were to view the sun through a very thin cloud made up of identical spherical droplets with x of order 100 or less, you would see a series of closely spaced rings immediately surrounding the light source. Moreover, because the precise angular position of the rings depends on wavelength, the rings would be brightly colored. This optical feature is known as a *corona*.

Coronas observed in real clouds are more diffuse, and less brightly colored, than the corona you would expect from a cloud composed of identical droplets. In fact, one reason colored coronas are rarely observed at all is because few clouds have a sufficiently narrow distribution of drop sizes.⁷

Far more commonly you will just see a diffuse circular bright patch surrounding the sun with little if any coloration. This feature represents a blending of both the forward diffraction peaks and the sidelobes contributed by a variety of different drop sizes.

⁷Another reason, of course, is that only true enthusiasts of optical phenomena take time each day — and risk their eyesight — in order to stare almost directly at the sun in the hope of spotting a spectacular corona!