# Session 1 Challenge: The FDTD Method Demystified

Mie scattering describes the interaction of electromagnetic waves, such as light, with small particles whose dimensions are comparable to the wavelength of the incident light. This theory, named after German physicist Gustav Mie, provides an exact solution to Maxwell's equations for the scattering of electromagnetic waves by spherical particles.

From Mie theory, we can calculate the scattering cross section of single homogeneous (or core/shell) spheres ($C_{sca}$) as

$$C_{sca} = \frac{2\pi}{k^2} \sum_n (2n+1) \left( |a_n|^2 + |b_n|^2 \right),$$

where $k$ is the wave number, $a_n$ and $b_n$ are the electric and magnetic Mie coefficients, and $n$ is the order of the multipole moments [1]. The scattering cross section relates the incident irradiance ($I_i$) and the energy scattering rate ($W_{sca}$) by $S_{sca} = W_{sca}/I_i$.

The ratio between $C_{sca}$ and the particle cross-sectional area projected onto a plane perpendicular to the incident beam ($G$) results in the **scattering efficiency** [1]:

$$Q_{sca} = \frac{C_{sca}}{G}.$$

In the following activities, you will calculate the **scattering efficiency** of **dielectric nanospheres** using the **FDTD method** and an **analytical solution** provided by the PyMieScatt package.

## Activity Description

Using the session notebook as a reference, calculate the scattering efficiency considering a single core-shell sphere nanoparticle. The core material is silicon ($n_{si} = 3.48$) with a diameter of 0.15 $\mu m$, and the shell is made of silica ($n_{sio2} = 1.45$) with a thickness of 0.075 $\mu m$. Keep the TFSF source, but set it to wavelengths from 0.45 $\mu m$ to 0.75 $\mu m$. Use 150 points to sample the optical response.

You can develop this example using the Tidy3D Python notebook or the Graphical User Interface (GUI) web-based environments.

You can use the code below as a reference to calculate the scattering efficiency. It calculates the refractive indices from the sphere core ( `sphere_mat_core` ) and shell ( `sphere_mat_shell` ) mediums, light wavelengths ( `lamdbas * 1e3` ), core ( `sphere_d_core` ) and shell ( `sphere_d_shell` ) diameters.

In [11]:
```
# Sphere core refractive indices.
sphere_n_core = np.sqrt(sphere_mat_core.eps_model(td.C_0 / lambdas))

# Sphere shell refractive indices.
sphere_n_shell = np.sqrt(sphere_mat_shell.eps_model(td.C_0 / lambdas))
```

```
# Compute the Mie efficiency from the analytical Mie theory.
Q_sca = []
for n_core, n_shell, wl in zip(sphere_n_core, sphere_n_shell, lambdas * 1e3):
    Q_sca.append(pms.MieQCoreShell(
        n_core, n_shell, wavelength=wl, dCore=sphere_d_core * 1e3, dShell=sph
    )

Q_sca_analytical = np.asarray(Q_sca)
```

## References

[1] Craig F. Bohren and Donald R. Huffman. Absorption and Scattering of Light by Small Particles. John Wiley & Sons, Ltd; 1998. doi:10.1002/9783527618156