= 234 / d + 10 for SWNT or ?RBM =
248 / d for DWNT , which is very useful in deducing the CNT diameter from the RBM position . Typical RBM range is 100 ? 350 cm ? 1 . If RBM intensity is particularly strong , its weak second overtone can be observed at double frequency .

= = = Bundling mode = = =

The bundling mode is a special form of RBM supposedly originating from collective vibration in a bundle of SWCNTs .

= = = G mode = = =

Another very important mode is the G mode ( G from graphite ) . This mode corresponds to planar vibrations of carbon atoms and is present in most graphite @-@ like materials . G band in SWCNT is shifted to lower frequencies relative to graphite ( 1580 cm ? 1 ) and is split into several peaks . The splitting pattern and intensity depend on the tube structure and excitation energy ; they can be used , though with much lower accuracy compared to RBM mode , to estimate the tube diameter and whether the tube is metallic or semiconducting .

= = = D mode = = =

D mode is present in all graphite @-@ like carbons and originates from structural defects . Therefore , the ratio of the G / D modes is conventionally used to quantify the structural quality of carbon nanotubes . High @-@ quality nanotubes have this ratio significantly higher than 100 . At a lower functionalisation of the nanotube , the G / D ratio remains almost unchanged . This ratio gives an idea of the functionalisation of a nanotube .

= = = G ' mode = = =

The name of this mode is misleading : it is given because in graphite , this mode is usually the second strongest after the G mode . However , it is actually the second overtone of the defect @-@ induced D mode ( and thus should logically be named D ' ) . Its intensity is stronger than that of the D mode due to different selection rules . In particular , D mode is forbidden in the ideal nanotube and requires a structural defect , providing a phonon of certain angular momentum , to be induced . In contrast , G ' mode involves a " self @-@ annihilating " pair of phonons and thus does not require defects . The spectral position of G ' mode depends on diameter , so it can be used roughly to estimate the SWCNT diameter . In particular , G ' mode is a doublet in double @-@ wall carbon nanotubes , but the doublet is often unresolved due to line broadening .
Other overtones , such as a combination of RBM + G mode at ~ 1750 cm ? 1 , are frequently seen in CNT Raman spectra . However , they are less important and are not considered here .

= = = Anti @-@ Stokes scattering = = =

All the above Raman modes can be observed both as Stokes and anti @-@ Stokes scattering . As mentioned above , Raman scattering from CNTs is resonant in nature , i.e. only tubes whose band gap energy is similar to the laser energy are excited . The difference between those two energies , and thus the band gap of individual tubes , can be estimated from the intensity ratio of the Stokes / anti @-@ Stokes lines . This estimate however relies on the temperature factor ( Boltzmann factor ) , which is often miscalculated ? a focused laser beam is used in the measurement , which can locally heat the nanotubes without changing the overall temperature of the studied sample .

= = Rayleigh scattering = =

Carbon nanotubes have very large aspect ratio , i.e. , their length is much larger than their diameter . Consequently , as expected from the classical electromagnetic theory , elastic light scattering ( or Rayleigh scattering ) by straight CNTs has anisotropic angular dependence , and from its spectrum , the band gaps of individual nanotubes can be deduced .

Another manifestation of Rayleigh scattering is the " antenna effect " , an array of nanotubes standing on a substrate has specific angular and spectral distributions of reflected light , and both those distributions depend on the nanotube length .