In this section of Resonance, we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. "Classroom" is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.

Quantum Theory of the Doppler Effect

Generally text books give only the wave theory of the Doppler effect. It is instructive to consider the same phenomenon in the quantum theory, allowing for the effects of special relativity. Let \( M \) be the mass of the source and \( V \) its velocity before photon emission. When a photon is emitted by the source, the internal energy \( E \) changes to \( E' \). We define \( v_0 = \frac{E - E'}{h} \). As a result of photon emission the source experiences a recoil, and hence its velocity changes to \( V' \) (Figure 1). In the relativistic case the change in the internal energy of the source, is nothing but the energy associated with the change in the rest mass of the source. If the rest masses of the source before and after photon emission be \( M \) and \( M' \) respectively, then \( (E - E') = (M - M') c^2 \).

Now momentum conservation leads to

\[
\frac{MV}{\sqrt{1 - \beta^2}} = \frac{M'V'}{\sqrt{1 - \beta'^2}} \cos \phi + \frac{hv}{c} \cos \Theta,
\]

\[
0 = \frac{M'V'}{\sqrt{1 - \beta'^2}} \sin \phi - \frac{hv}{c} \sin \Theta,
\]
Further, energy conservation gives

\[ \frac{Mc^2}{\sqrt{1 - \beta^2}} = \frac{M'c^2}{\sqrt{1 - \beta'^2}} + hv. \]

In these equations \( \beta = V/c, \beta' = V'/c \) and \( c \) is the velocity of light. Also \( \Theta \) is the angle between the direction of the initial velocity \( V \) and the direction of the light emission and \( \phi \) is the angle between the directions of \( V \) and \( V' \). Eliminating \( M', V' \) and \( \phi \), we get

\[ \frac{Mc^2 \nu}{\sqrt{1 - \beta^2}} (1 - \beta \cos \Theta) = Mc^2 \nu_0 - \frac{h\nu_0^2}{2}. \]

If the mass \( M \) of the source is sufficiently large compared to the photonic mass \( (h\nu_0/c^2) \) of light then we can neglect the last term to get:

\[ \nu = \nu_0 \frac{\sqrt{1 - \beta^2}}{1 - \beta \cos \Theta}. \]

It is important to note that \( \nu \neq \nu_0 \) even when \( \Theta = \pi/2 \). This is the famous relativistic transverse Doppler effect. Incidentally we get the well known result of the non-relativistic Doppler effect when