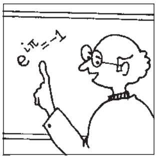
Classroom



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

G S Ranganath, Raman Research Institute, Bangalore 560 080

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 $\nu_0 = \frac{E-E'}{h}$. 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

$$\frac{MV}{\sqrt{1-\beta^2}} = \frac{M'V'}{\sqrt{1-\beta^2}}\cos\phi + \frac{h\nu}{c}\cos\Theta ,$$

$$0 = \frac{M'V'}{\sqrt{1-\beta'^2}}\sin\phi - \frac{h\nu}{c}\sin\Theta,$$

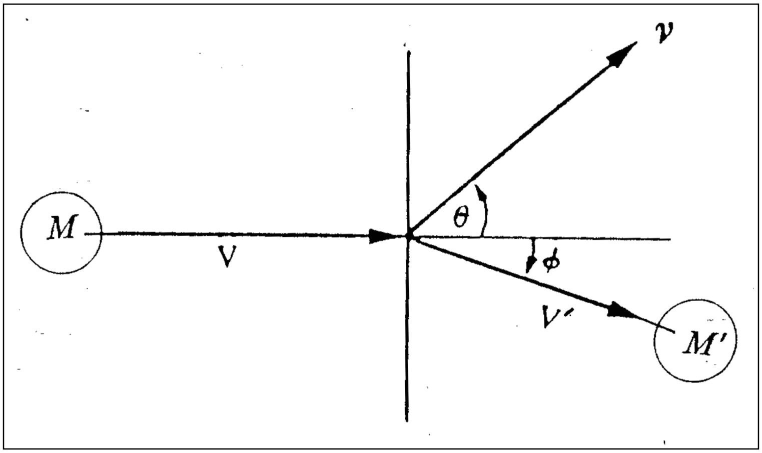


Figure 1 Quantum theory of the Doppler effect.

Further, energy conservation gives

$$\frac{Mc^2}{\sqrt{1-\beta^2}} = \frac{M'c^2}{\sqrt{1-\beta^2}} + h\nu \, .$$

In these equations $\beta = V/c$, $\beta' = V'/c$ and c is the velocity of light. Also Θ is the angle between the direction of the initial velocity V and the direction of the light emission and ϕ is the angle between the directions of V and V' Eliminating M', V' and ϕ, 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

$\Theta = 0$ and β^2 is negligible compared to unity. This theory is rather reminiscent of the Compton theory of X-ray scattering by electrons.

We can easily generalize this theory to discuss the Doppler effect in a medium. If the refractive index of the medium is μ then we change β to $\mu\beta$. An interesting possibility in a medium is that the source can move with a velocity greater than the velocity of light in that medium i. e., $V > c/\mu$. Then a careful analysis leads to the surprising result that even if the source is not initially excited, it will be excited with the simultaneous emission of photons inside the Cherenkov cone $(\Theta < \Theta_0 = \cos^{-1}(\frac{1}{\mu\beta}))$. Then the excited source will make a transition to the lower state emitting photons outside the Cherenkov cone $(\Theta > \Theta_0)$. This is not a paradoxical result since the energy needed for exciting the source and for the emission of the photon are both derived from the kinetic energy of the source.

Suggested Reading

- **V L Ginzburg, L M Levin, M S Rabinovich and D V Sivukhin. *Problems in undergraduate physics*. Pergamon Press, 1965.**
- **V L Ginzburg. *Waynflete Lectures on Physics*. Pergamon Press, 1983.**

! Microbiology as if Bird Watching

Milind G Watve, M.E. Society, Abasaheb Garware College, Karve Road, Pune 411 004, India.

I became a bird-watcher much before I started studying Microbiology for my Bachelor's. I wasn't sure why I opted for Microbiology. Perhaps just by default, since in those days, there were few options for a student not going into medicine. I was equally uncertain about taking bird-watching seriously. It just so happened that one of our instructors, in a sort of hobby-club to which I subscribed in my high school days, took us bird watching once or twice. Somehow, this hobby lingered on and became more and more absorbing. Today I can say with confidence that if I am a good microbiologist, it is because of bird-watching.