Kink Solitons in Nonlinear Optics

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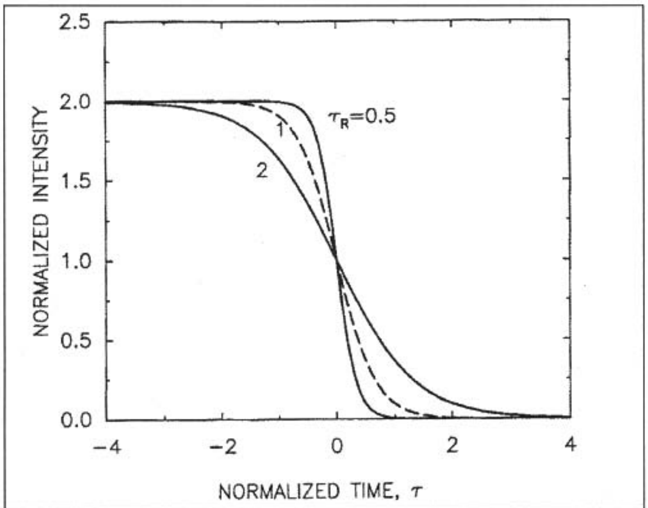
In the last few years the word "soliton" has become a common word in optics and photonics, thanks to the current worldwide study of potential applications of solitons in optical communications and photonic switching.[1] Even though the phenomenon of self-induced transparency in a resonant absorbing medium provided the first example of solitons in optics, it was the discovery of solitons in optical fibers that transformed solitons from a mathematical curiosity into a practical and useful entity. Their existence is attributed to the simultaneous presence of anomalous dispersion and nonlinear refraction (responsible for self-phase modulation) in the 1.5 μm wavelength region of silica fibers.[2]

It was discovered in 1973 that optical fibers can support a different kind of soliton in the normal-dispersion region. These solitons appear in the form of a dip against a uniform background and are called "dark" solitons since their presence is marked by the absence of light, in contrast with the pulse-like bright solitons. Dark solitons have been observed experimentally and have attracted considerable attention in recent years.[2]

Mathematically, a third kind of soliton known as the kink soliton can exist.[3] Although kink solitons occur in many branches of physics (*e.g.*, particle physics and solid state physics), their occurrence in nonlinear optics is relatively rare. It is only recently that the possibility of kink solitons in optical fibers has been discovered.[4]

Kink solitons owe their existence to the phenomenon of stimulated Raman scattering (SRS). With the inclusion of SRS, wave propagation in optical fibers is governed by a generalized nonlinear Schrödinger equation that in its normalized form is given by[4]



Temporal profiles of an optical shock representing kink solitons for several values of τ_R.

$$i\frac{\partial U}{\partial \xi} + \frac{1}{2}\frac{\partial^2 U}{\partial \tau^2} + N^2|U|^2U - N^2\tau_R U\frac{\partial |U|^2}{\partial \tau} = 0, \tag{1}$$

where the parameters N and τ_R govern the effects of self-phase modulation and SRS, respectively. In the absence of the SRS term, Eq. (1) has the well-known bright-soliton solution $U(\tau) = \text{sech}(\tau)$ when $N = 1$. In the presence of SRS, Eq. (1) supports neither bright nor dark solitons. However, it is found to have the following kink-soliton solution:

$$U(\tau) = \exp\left(-\frac{3\tau}{4\tau_R}\right)\sqrt{\text{sech}\left(\frac{3\tau}{2\tau_R}\right)} \tag{2}$$

with $N = 3/(4\tau_R)$. In the present context, the kink soliton represents an optical front or optical shock that preserves its shape when propagating through an optical fiber. The figure shows the shock profiles by plotting $U^2(\tau)$ for several values of τ_R. The steepness of the shock depends on the parameter τ_R. The shock front becomes increasingly steep as τ_R is reduced. The power level P_0 (defined as the power at $\tau = 0$) is estimated to be in the range 1-10 kW. The qualitative features of the intensity profiles shown in the figure remain unchanged when self-steepening is included.[4] Recently, shock-type solitary-wave solutions were also obtained for the case of nonlinear interaction of two waves in a Raman medium.[5] The experimental observation of such solitons would be of considerable interest.

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