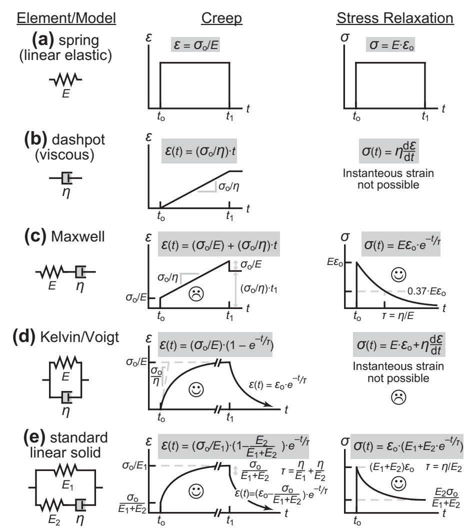

FIGURE 3.9 Common viscoelastic constitutive models for viscoelastic creep and stress relaxation, due to an instantaneous and constant applied stress (σ_o) and strain (ε_o), respectively, including (a) a spring element, (b) a dashpot element, (c) the Maxwell model, (d) the Kelvin or Voigt model, and (e) the standard linear solid model, where t is time, E is the elastic modulus of spring elements, η is the viscosity of dashpot elements, and τ is the relaxation time.

during creep or strain recovery is not realistic, and stress relaxation does not necessarily decay to zero (Fig. 3.9c). Conversely, the classic *Kelvin* or *Voigt model* combines a spring and dashpot in parallel to model viscoelastic creep, but stress relaxation is not possible and creep deformation may be erroneous at short times (Fig. 3.9d). By combining the strengths of the Maxwell and Kelvin models, the *standard linear solid model* (a.k.a., the three-parameter model) provides a good approximation of both creep and stress relaxation for the most linear viscoelastic polymers (Fig. 3.9e), although the stress relaxation may be more rapid than reality as has been shown for bone tissue [97]. In each of the above models, creep and stress relaxation are most accurately modeled by an exponential rise and decay, respectively, characterized by a time constant or *relaxation time* (τ), which is a function of spring stiffness and dashpot viscosity. The *Burgers model* (a.k.a., four-parameter model) also combines the Maxell and Voigt models in series and is popular. The *generalized Maxwell*