

11-5 The Yo-Yo

A yo-yo is a physics lab that you can fit in your pocket. If a yo-yo rolls down its string for a distance h , it loses potential energy in amount mgh but gains kinetic energy in both translational ($\frac{1}{2}Mv_{\text{com}}^2$) and rotational ($\frac{1}{2}I_{\text{com}}\omega^2$) forms. As it climbs back up, it loses kinetic energy and regains potential energy.

In a modern yo-yo, the string is not tied to the axle but is looped around it. When the yo-yo “hits” the bottom of its string, an upward force on the axle from the string stops the descent. The yo-yo then spins, axle inside loop, with only rotational kinetic energy. The yo-yo keeps spinning (“sleeping”) until you “wake it” by jerking on the string, causing the string to catch on the axle and the yo-yo to climb back up. The rotational kinetic energy of the yo-yo at the bottom of its

string (and thus the sleeping time) can be considerably increased by throwing the yo-yo downward so that it starts down the string with initial speeds v_{com} and ω instead of rolling down from rest.

To find an expression for the linear acceleration a_{com} of a yo-yo rolling down a string, we could use Newton’s second law just as we did for the body rolling down a ramp in Fig. 11-8. The analysis is the same except for the following:

1. Instead of rolling down a ramp at angle θ with the horizontal, the yo-yo rolls down a string at angle $\theta = 90^\circ$ with the horizontal.
2. Instead of rolling on its outer surface at radius R , the yo-yo rolls on an axle of radius R_0 (Fig. 11-9a).
3. Instead of being slowed by frictional force \vec{f}_r , the yo-yo is slowed by the force \vec{T} on it from the string (Fig. 11-9b).

The analysis would again lead us to Eq. 11-10. Therefore, let us just change the notation in Eq. 11-10 and set $\theta = 90^\circ$ to write the linear acceleration as

$$a_{\text{com}} = -\frac{g}{1 + I_{\text{com}}/MR_0^2}, \quad (11-13)$$

where I_{com} is the yo-yo’s rotational inertia about its center and M is its mass. A yo-yo has the same downward acceleration when it is climbing back up.

11-6 Torque Revisited

In Chapter 10 we defined torque τ for a rigid body that can rotate around a fixed axis, with each particle in the body forced to move in a path that is a circle cen-

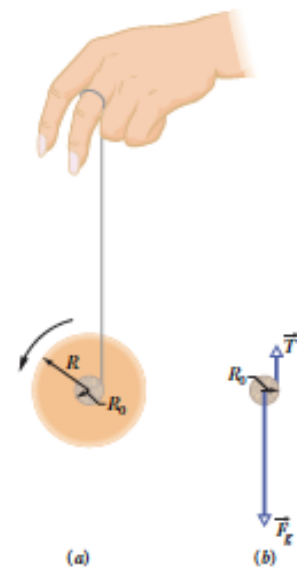


Fig. 11-9 (a) A yo-yo, shown in cross section. The string, of assumed negligible thickness, is wound around an axle of radius R_0 . (b) A free-body diagram for the falling yo-yo. Only the axle is shown.