

## Constant force action

This is the Lagrangian for a particle in a region of constant force  $F$ .

$$L = \frac{m\dot{x}^2}{2} + Fx$$

Show that

$$S = \int_0^T L dt = \frac{m(x_b - x_a)^2}{2T} + \frac{FT(x_b + x_a)}{2} - \frac{F^2 T^3}{24m}, \quad T = t_b - t_a$$

The first step is to derive  $x(t)$  and  $\dot{x}(t)$  from  $L$  and the Euler-Lagrange equation

$$\frac{d}{dt} \frac{\partial L}{\partial \dot{x}} = \frac{\partial L}{\partial x}$$

From  $L$  we have

$$\frac{d}{dt} \frac{\partial L}{\partial \dot{x}} = m\ddot{x}, \quad \frac{\partial L}{\partial x} = F$$

and by Euler-Lagrange

$$\ddot{x} = \frac{F}{m}$$

Note that

$$\frac{d^2}{dt^2} \left( \frac{Ft^2}{2m} + At + B \right) = \frac{F}{m} = \ddot{x}$$

Hence  $x(t)$  is quadratic.

$$x(t) = \frac{Ft^2}{2m} + At + B$$

These are the boundary conditions.

$$x(0) = x_a, \quad x(T) = x_b$$

Solve for  $B$ .

$$x(0) = B = x_a$$

Solve for  $A$ .

$$x(T) - x(0) = \frac{FT^2}{2m} + AT = x_b - x_a$$

Hence

$$A = \frac{x_b - x_a}{T} - \frac{FT}{2m}$$

Substitute  $A$  and  $B$  into  $x(t)$ .

$$x(t) = \frac{Ft^2}{2m} + \frac{(x_b - x_a)t}{T} - \frac{FTt}{2m} + x_a \quad (1)$$

Take the time derivative of  $x(t)$  to obtain  $\dot{x}(t)$ .

$$\dot{x}(t) = \frac{d}{dt}x(t) = \frac{Ft}{m} + \frac{x_b - x_a}{T} - \frac{FT}{2m} \quad (2)$$

The action is

$$\begin{aligned} S &= \int_0^T L \, dt \\ &= \int_0^T \left( \frac{m\dot{x}^2}{2} + Fx \right) dt \\ &= \frac{m(x_b - x_a)^2}{2T} + \frac{FT(x_b + x_a)}{2} - \frac{F^2T^3}{24m} \end{aligned} \tag{3}$$

Eigenmath script