

2-3. Find S_{cl} for a particle under a constant force f , that is,

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

We will need (2.7) to determine the classical equation of motion $x(t)$.

$$\frac{d}{dt} \frac{\partial L}{\partial \dot{x}} = \frac{\partial L}{\partial x} \quad (2.7)$$

For the Lagrangian L given in problem 2-3 we have

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

By equation (2.7) we have for the classical acceleration $\ddot{x}(t)$

$$\ddot{x}(t) = \frac{f}{m}$$

Hence $x(t)$ must have the following quadratic form.

$$x(t) = \frac{f}{2m}t^2 + Bt + C \quad (1)$$

We have the following boundary conditions.

$$x(t_a) = x_a \quad x(t_b) = x_b$$

Subtract boundary conditions to solve for B .

$$x(t_b) - x(t_a) = x_b - x_a = \frac{f}{2m}(t_b^2 - t_a^2) + B(t_b - t_a)$$

Solve for B .

$$B = \frac{x_b - x_a}{t_b - t_a} - \frac{f(t_b^2 - t_a^2)}{2m(t_b - t_a)} \quad (2)$$

Solve for C .

$$\begin{aligned} C &= x_a - \frac{f}{2m}t_a^2 - Bt_a \\ &= \frac{f(t_at_b^2 - t_a^2t_b)}{2m(t_b - t_a)} + \frac{t_bx_a - t_ax_b}{t_b - t_a} \end{aligned} \quad (3)$$

Substitute (2) and (3) into (1) to obtain

$$x(t) = \frac{f}{2m}t^2 + \left(\frac{x_b - x_a}{t_b - t_a} - \frac{f(t_b^2 - t_a^2)}{2m(t_b - t_a)} \right) t + \frac{f(t_a t_b^2 - t_a^2 t_b)}{2m(t_b - t_a)} + \frac{t_b x_a - t_a x_b}{t_b - t_a} \quad (4)$$

Equation (4) is too complicated to continue so translate the time coordinate as follows.

$$t_a = 0 \quad t_b = T$$

We now have

$$x(t) = \frac{ft^2}{2m} + \left(\frac{x_b - x_a}{T} - \frac{fT}{2m} \right) t + x_a \quad (5)$$

Differentiate $x(t)$ to obtain velocity $\dot{x}(t)$.

$$\dot{x}(t) = \frac{d}{dt}x(t) = \frac{ft}{m} - \frac{fT}{2m} + \frac{x_b - x_a}{T} \quad (6)$$

Substitute (5) and (6) into L .

$$\begin{aligned} L &= \frac{m}{2}\dot{x}^2 + fx \\ &= \frac{f^2}{m}t^2 + \left(\frac{2f(x_b - x_a)}{T} - \frac{f^2T}{m} \right) t + \frac{f^2T^2}{8m} + \frac{f(3x_a - x_b)}{2} + \frac{m(x_b - x_a)^2}{2T^2} \end{aligned} \quad (7)$$

Integrate (7) to obtain S_{cl} .

$$S_{cl} = \int_0^T L dt = \frac{m(x_b - x_a)^2}{2T} + \frac{fT(x_b + x_a)}{2} - \frac{f^2T^3}{24m} \quad (8)$$

where $T = t_b - t_a$.