

## Homework 3

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## 1 Goldstein 8.1

## 1.1 Part (a)

The Hamiltonian is given by

$$H(q_i, p_i, t) = p_i \dot{q}_i - L(q_i, \dot{q}_i, t) \quad (1)$$

where all the  $\dot{q}_i$ 's on the RHS are to be expressed in terms of  $q_i$ ,  $p_i$  and  $t$ . Now,

$$dH = \frac{\partial H}{\partial q_i} dq_i + \frac{\partial H}{\partial p_i} dp_i + \frac{\partial H}{\partial t} dt \quad (2)$$

From (1),

$$\begin{aligned} dH &= p_i d\dot{q}_i + \dot{q}_i dp_i - dL \\ &= p_i d\dot{q}_i + \dot{q}_i dp_i - \left( \frac{\partial L}{\partial q_i} dq_i + \frac{\partial L}{\partial \dot{q}_i} d\dot{q}_i + \frac{\partial L}{\partial t} dt \right) \\ &= -\frac{\partial L}{\partial q_i} dq_i + \dot{q}_i dp_i + \left( p_i - \frac{\partial L}{\partial \dot{q}_i} \right) d\dot{q}_i - \frac{\partial L}{\partial t} dt \end{aligned} \quad (3)$$

Comparing (2) and (3) we get

$$\frac{\partial H}{\partial q_i} = -\frac{\partial L}{\partial q_i} = -\dot{p}_i \quad (\text{2nd equality from Hamilton's equation}) \quad (4)$$

$$\dot{q}_i = \frac{\partial H}{\partial p_i} \quad (\text{also Hamilton's equation}) \quad (5)$$

$$p_i - \frac{\partial L}{\partial \dot{q}_i} = 0 \quad (\text{H is not explicitly dependent on } \dot{q}_i) \quad (6)$$

$$-\frac{\partial L}{\partial t} = \frac{\partial H}{\partial t} \quad (7)$$

From (4) and (6) we have

$$\frac{d}{dt} \left( \frac{\partial L}{\partial \dot{q}_i} \right) - \frac{\partial L}{\partial q_i} = 0, \quad i = 1, 2, \dots, n \quad (8)$$

which are the Euler-Lagrange equations.

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