Theoretical Dynamics September 24, 2010

Homework 3

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1 Goldstein 8.1

1.1 Part (a)

The Hamiltonian is given by

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

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

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

From (1),

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

Comparing (2) and (3) we get

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

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

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

$$-\frac{\partial L}{\partial t} = \frac{\partial H}{\partial t} \tag{7}$$

From (4) and (6) we have

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

which are the Euler-Lagrange equations.

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