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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Table of Contents Goldstein Classical Mechanics Solutions Chapter 8

1. Understanding the eBook Goldstein Classical Mechanics Solutions Chapter 8
    - The Rise of Digital Reading Goldstein Classical Mechanics Solutions Chapter 8
    - Advantages of eBooks Over Traditional Books
2. Identifying Goldstein Classical Mechanics Solutions Chapter 8
    - Exploring Different Genres
    - Considering Fiction vs. Non-Fiction
    - Determining Your Reading Goals
3. Choosing the Right eBook Platform
    - Popular eBook Platforms
    - Features to Look for in an Goldstein Classical Mechanics Solutions Chapter 8
    - User-Friendly Interface
4. Exploring eBook Recommendations from Goldstein Classical Mechanics Solutions Chapter 8
    - Personalized Recommendations
    - Goldstein Classical Mechanics Solutions Chapter 8 User Reviews and Ratings
    - Goldstein Classical Mechanics Solutions Chapter 8 and Bestseller Lists
5. Accessing Goldstein Classical Mechanics Solutions Chapter 8 Free and Paid eBooks
    - Goldstein Classical Mechanics Solutions Chapter 8 Public Domain eBooks
    - Goldstein Classical Mechanics Solutions Chapter 8 eBook Subscription Services
    - Goldstein Classical Mechanics Solutions Chapter 8 Budget-Friendly Options

6. Navigating Goldstein Classical Mechanics Solutions Chapter 8 eBook Formats
    - ePub, PDF, MOBI, and More
    - Goldstein Classical Mechanics Solutions Chapter 8 Compatibility with Devices
    - Goldstein Classical Mechanics Solutions Chapter 8 Enhanced eBook Features
7. Enhancing Your Reading Experience
    - Adjustable Fonts and Text Sizes of Goldstein Classical Mechanics Solutions Chapter 8
    - Highlighting and Note-Taking Goldstein Classical Mechanics Solutions Chapter 8
    - Interactive Elements Goldstein Classical Mechanics Solutions Chapter 8
8. Staying Engaged with Goldstein Classical Mechanics Solutions Chapter 8
    - Joining Online Reading Communities
    - Participating in Virtual Book Clubs
    - Following Authors and Publishers Goldstein Classical Mechanics Solutions Chapter 8
9. Balancing eBooks and Physical Books Goldstein Classical Mechanics Solutions Chapter 8
    - Benefits of a Digital Library
    - Creating a Diverse Reading Collection Goldstein Classical Mechanics Solutions Chapter 8
10. Overcoming Reading Challenges
    - Dealing with Digital Eye Strain
    - Minimizing Distractions
    - Managing Screen Time
11. Cultivating a Reading Routine Goldstein Classical Mechanics Solutions Chapter 8
    - Setting Reading Goals Goldstein Classical Mechanics Solutions Chapter 8
    - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Goldstein Classical Mechanics Solutions Chapter 8
    - Fact-Checking eBook Content of Goldstein Classical Mechanics Solutions Chapter 8
    - Distinguishing Credible Sources
13. Promoting Lifelong Learning
    - Utilizing eBooks for Skill Development
    - Exploring Educational eBooks
14. Embracing eBook Trends
    - Integration of Multimedia Elements

- Interactive and Gamified eBooks

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