VP160 Recitation Class VI

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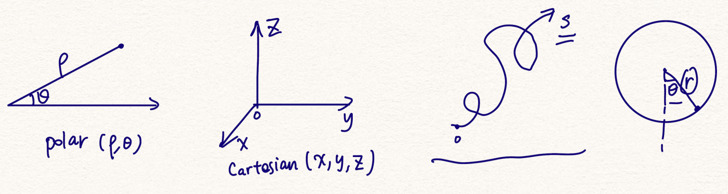
Generalized coordinates

Any coordinates describing motions.

e.g.



$$\begin{cases} q_1(t) \\ q_2(t) \\ \dots \\ q_n(t) \end{cases} \Rightarrow \begin{cases} \dot{q_1}(t) \\ \dot{q_2}(t) \\ \dots \\ \dot{q_n}(t) \end{cases} \text{(generalized velocity)}$$

Degree of freedom (usually denoted by f)

The minimum number of independent generalized coordinates needed to describe the system's motions.

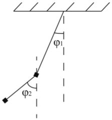
In general,

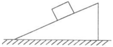
$$f = 3N - m$$

where N is the number of particles, and m is the number of constraints (number of equations that relate unknowns).

Exercise 1

Find the degree of freedom:





(a) (b)

Hamilton's Principle

$$\text{Real path} \iff \delta S = 0$$

(δ: variational differential, S is a functional: a function that maps functions into numbers.)

$\Downarrow$ How?

Euler-Lagrange Equation

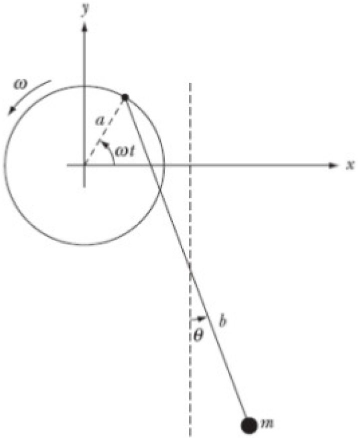
For $i = 1, 2, ..., f$:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \frac{\partial L}{\partial q_i} = 0$$

Learn more about variational and how to derive Hamilton's Principle, visit
https://zhuanlan.zhihu.com/p/126115834
https://zhuanlan.zhihu.com/p/139018146

Exercise 2

A simple pendulum of length b and mass m moves attached to a massless rim of radius a rotating with constant angular velocity ω. How many degrees of freedom do we have here? Find the Lagrangian.



Exercise 3

Find the equations of motion of a particle of mass m constrained to move on the surface of a sphere, acted upon a conservative force $\mathbf{F} = F_0 \hat{n}_\theta$ with F_0 a constant.

Hint. To find the potential energy find the scalar product $\mathbf{F} \cdot d\mathbf{r}$ for the infinitesimal displacement on the sphere and use the fact that it is equal to $-dU$ (the force is conservative).

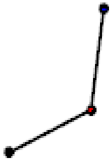
Exercise 4

Double pendulum:

(1) identify the generalized coordinates;

(2) find the Lagrangian;

(3) write down the Euler-Lagrange equations of motion;



Definition

$$\vec{p} = m\vec{v}$$

Rewrite Newton's second law

$$\vec{F} = \frac{d\vec{p}}{dt}$$

(when m is not varying, $F = m\frac{d\vec{v}}{dt} = m\vec{a}$)

Impulse Theorem

$$\vec{p_2} - \vec{p_1} = \int_{t_1}^{t_2} \vec{F} dt$$

- If $\vec{F_{ext}} = 0$, for a system, $\Delta\vec{p} = 0 \Leftrightarrow p = \text{Const}$ (Conservation of momentum)

Application of Conservative of Momentum

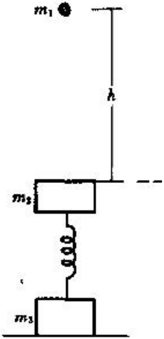
- Non-central Collision (e.g. explosion)

$$\vec{p_{before}} = \vec{p_{after}}$$

- Central Collision
  - Elastic
    - $e = (\vec{v_2}' - \vec{v_1}')/(\vec{v_1} - \vec{v_2}) = 1$
    - Conservation of energy
  - Inelastic
    - $e < 1$
    - Energy loss
  - Completely Inelastic
    - $e = 0$
    - stick to each other

Exercise 5

Assume m_1, m_2, m_3, k is known. Release m_1, the collision between m_1 and m_2 is completely inelastic. Find h so that m_3 can just leave the ground.



Center of Mass

$$r_C = \frac{\sum m_i r_i}{\sum m_i}$$

$$r_C = \frac{\int r_i dm}{\int dm}$$

Pappus Law

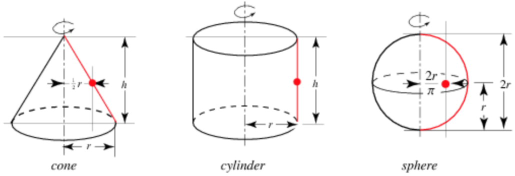
First Theorem:

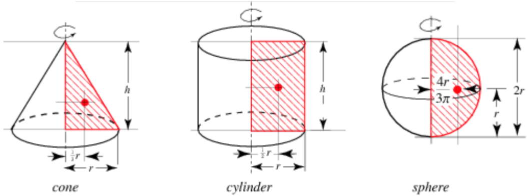
$$S = 2\pi s x$$

Second Theorem:

$$V = 2\pi A x$$

where x is the distance from the reference axis and the center of mass.





- An important fact:

$$\vec{F_{ext}} = 0 \Leftrightarrow \vec{p} = Const \Leftrightarrow \vec{v_c} = Const$$

Rocket Propulsion

$$mv + Fdt = (m + dm)(v + dv) - udm$$

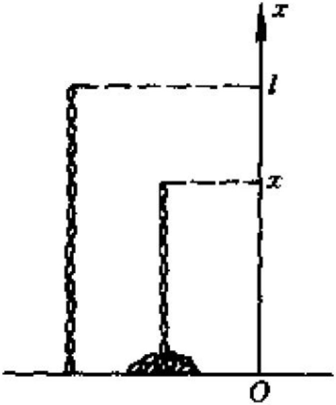
$$m\frac{dv}{dt} = (u - v)\frac{dm}{dt} + F$$

Reminder

What FoR are we looking at?

Exercise 6

A rope with length l and mass m is placed vertically. At the beginning, the lower end of the rope just touches the ground. Release the rope, find the support force of the ground with respect to x.



Reference

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