Civil Engineering I
-an introduction to structural mechanics-

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Civil Engineering I (CE I, #132024)

- Day/Period: Thu.2-3 (1st semester)
- Place: D51, Building for General Education(一般教養棟D51)
- Instructors: K. Kimoto and K. Yoshida

  (Dpet. of Civil & Env. Eng. 環境理工学部、環境デザイン工学科)
- Textbook: none (handouts will be given when necessary)
- Prerequisites: explained later
- Credit: 1
- Grade evaluation: based on class assignments, no term-end exam

Civil Engineering (CE)

- Civil Engineering is an engineering discipline that deals with the planning, design, construction, and management of civil infrastructures, such as roads, bridges, dams, tunnels, river banks, sewerage system, pipelines, transportation systems and others.

roads, highway

tunnels

dam

transportation system

. . .

Sub-Disciplines of CE

Scientific branches that CE is based upon is far-reaching,
but the core sub-disciplines are

- Materials' Science & Engineering
- Structural Engineering
- Hydraulic Engineering
- Geotechnical Engineering
- Transportation and Urban Planning Engineering
- Water Resource Engineering

construction materials

What you will learn in CE I

- Introduction to Structural Mechanics

  2h × 4 Classes, (Prof. Kimoto)

- Introduction to Hydraulic Mechanics

  2h × 4 Classes, (Prof. Yoshida)

Learning these subjects usually require 3 or more semesters with considerable amount of exercises.

- ☐ Please consider this course as a very brief introduction to structural and hydraulic mechanics.
- ☐ Only elementary topics will be discussed, thus the course isn't going to be an overview of the relevant field.

Structural Mechanics

- Is a branch of science that studies the action of forces to the load-bearing structures such as bridges, tunnels, and buildings.

- The objective of a structural analysis is to evaluate the strength, rigidity, stability of the structures of your interest.

- In the context of CE, theories and techniques of structural mechanics applies most directly to the designs of bridges.

Bridges are everywhere !

Where are they ?

If you look for, you’d notice there are a number of bridges out there.

bridge made of granite bars

Railway bridges
Railway tracks for Shinkansen (bullet train) are elevated 100%!

Pedestrian overpass

10 bridges are found on the way to my office

(if very short ones are included)

Bridges are important !

The reasons become obvious if you imagine that …

1. a bridge you use every day to get to your office/school is closed for a month due a repair work.
2. highway traffics are slowed down because an extensive renovation works is going on that the prices of fresh vegetables are getting higher.
3. you have an important job interview in Tokyo tomorrow. But, some of the bridges of JR Sanyo Shinkansen were damaged seriously due to an earthquake and it requires 6 months for them to be rebuilt.
4. the bridge that takes you to the nearest hospital has been closed due to aging, but you have grand parents who have health problems.
5. you are working for Okayama city and in charge of evacuating people in case of emergency. However, you know that a sever traffic jam would occur if one of the bridges spanning over Asahi river is damaged by flooding or earthquake.

Simply put, it would be very inconvenient if it weren’t for the bridges.
Even life-threatening problems could occur if our bridges are not reliable.

Sources of Loads

- Traffic load
- Self-weight
- Earthquake
- Wind
- Snow
- Temperature variation

Strength, Stiffness and Stability of the structure must be ensured

, which is no easy task to accomplish.

Basic Bridge Types (in the order of span)

Girder

Rigid frame (Rahmen)

Arch (伯方大橋)

Truss(港大橋)

Cable-stayed (多々羅大橋)

Suspension (下津井瀬戸大橋)

※span: pier-to-pier (tower-to-tower) distance

Structural Analysis

The objectives of a structural analysis is to evaluate the followings.

1. strength → must be strong enough and not to fail in a brittle manner
2. stiffness → must be sufficiently rigid and should not deform excessively
3. stability → should respond stably to dynamic loads(traffic, earthquake, wind). The perturbation should not be amplified

Scientific Basis of Structural Mechanics

- Structural mechanics has been built upon Newtonian mechanics pulse a minimal set of modelling assumptions.
- The assumptions are made based on the experiments performed to investigate the strength and stiffness of materials.
- Newtonian mechanics derives everything from 3 principles (Newton's laws of motion)
- In this course, we will see what we can tell about the balance of some simple structures (beam and truss) starting from the Newton's principles.

Newton’s laws of motion

Principles of Newtonian Mechanics (Newton's laws of Motion)

1) Existence of an inertia system

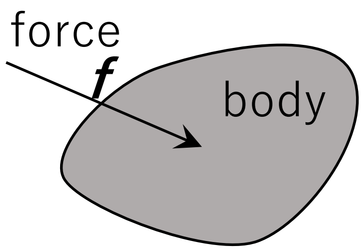
   There exists a coordinate system in which we can observe a body moves at an constant velocity when a force is not acting on it.

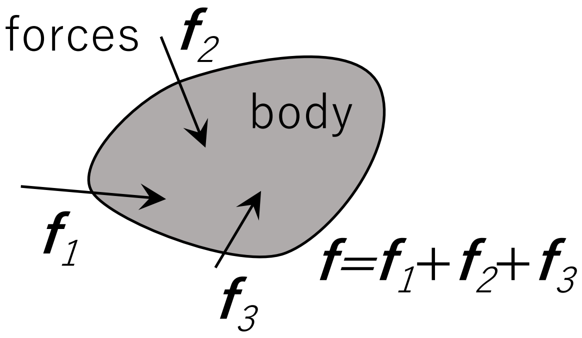
2) Conservation of linear momentum (equation of motion)

3) The law of action and reaction

The 2nd and 3rd laws are used primarily when working on mechanics problems.

The 2nd Law
(conservation of linear momentum)





The 2nd law is formulated as

$$\mathbf{f} = m\boldsymbol{a} \quad \text{———} \quad (1)$$ equation of motion

where m is mass, $\boldsymbol{f}$ is force and $\boldsymbol{a}$ is acceleration.

Note that

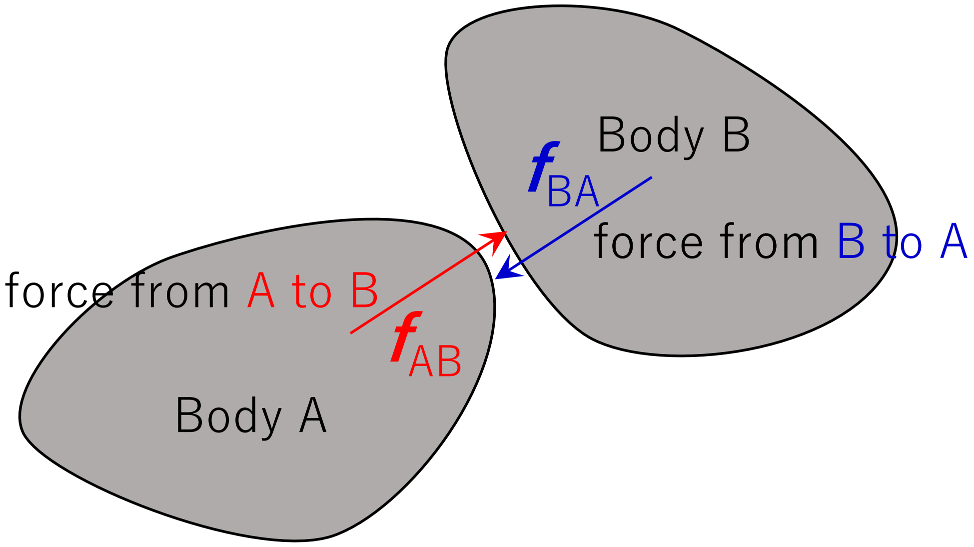
1. m is scalar while $\boldsymbol{f}$ and $\boldsymbol{a}$ are vector quantities.

2. $\boldsymbol{f}$ is the sum of all forces if multiple forces are acting on the body.

3. eq.(1) reduces to $\boldsymbol{f}=\mathbf{0}$ if the body is at rest, i.e. when $\boldsymbol{a}=\mathbf{0}$.

$$\mathbf{f} = \sum_{i=1}^{n} \mathbf{f}_i = \mathbf{o} \quad \text{———} \quad (1')$$ equilibrium equation

The 3rd Law



A pair of bodies pushing/pulling each other

The law of action and reaction:

If body A is pushing/pulling body B,
Then body B is pushing/pulling back A with a force of equal magnitude.

$$\boldsymbol{f}_{AB} + \boldsymbol{f}_{BA} = \boldsymbol{0}$$

(Vector sum)

Elementary Vector Algebra – brief review

Vector and Scalar quantities

- Scalars:

  temperature, mass, length, distance, voltage, mass concentration …

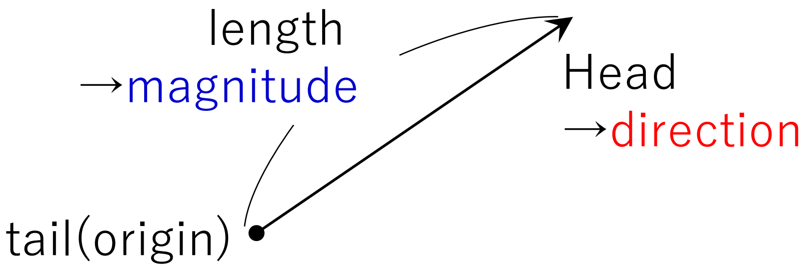
  only magnitude

- Vectors:

  force, velocity, displacement, acceleration, heat flux,..

  magnitude and direction

(i) Graphic representation



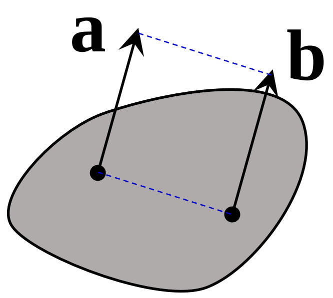
(ii) Symbolic representation

- Use boldface letters such as ***a***, ***f***, or ***v.***
- Magnitude of ***a*** is written as |***a***|

Some terminologies

- Vector identity

  Vector $\boldsymbol{a}$ is said to be equal to $\boldsymbol{b}$ and write $\boldsymbol{a}=\boldsymbol{b}$,
  if and only if they have the same magnitude and direction.



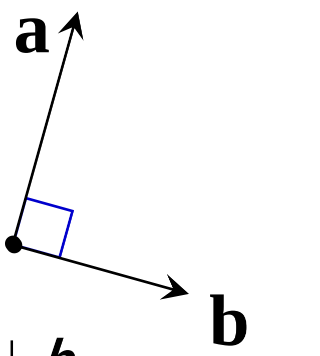
$\boldsymbol{a}$ and $\boldsymbol{b}$ are physically different, mathematically identical vectors

- Unit vector

  Vector $\boldsymbol{a}$ is said to be a unit vector when $|\boldsymbol{a}|=1$

- Mutually orthogonal vectors

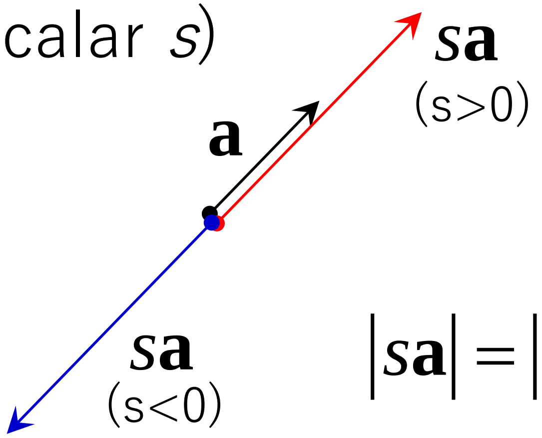
  A pair of vectors $\boldsymbol{a}$ and $\boldsymbol{b}$ is said to be mutually orthogonal and write $\boldsymbol{a}\perp\boldsymbol{b}$ if they make a right angle



$\boldsymbol{a}\perp\boldsymbol{b}$

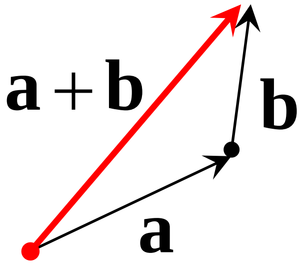
Basic Algebraic Operations on Vectors

1. Scalar multiplication ($s\boldsymbol{a}$: vector $\boldsymbol{a}$ multiplied by scalar s)
   - Gives you a new vector s times longer than $\boldsymbol{a}$.
   - The direction is reversed when $s < 0$.

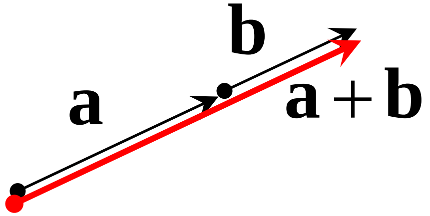


$$|s\mathbf{a}| = |s||\mathbf{a}|$$

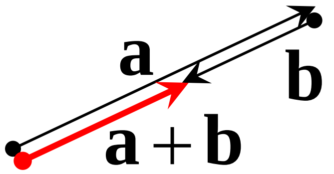
2. Vector addition ($\boldsymbol{a}+\boldsymbol{b}$: vector $\boldsymbol{a}$ plus vector $\boldsymbol{b}$)
   - Connect two given vectors.
   - The order of summation does not matter (commutativity)



$$|\mathbf{a}+\mathbf{b}| \neq |\mathbf{a}| + |\mathbf{b}|$$



$$|\mathbf{a}+\mathbf{b}| = |\mathbf{a}| + |\mathbf{b}|$$



$$|\mathbf{a}+\mathbf{b}| = |\mathbf{a}| - |\mathbf{b}|$$

Vector Addition is Associative

We can add more than two vectors by summing two vectors repeatedly, e.g.

$\mathbf{a}+(\mathbf{b}+\mathbf{c})$ Add ***b*** and ***c*** first, then add ***a*** to the resultant

$(\mathbf{a}+\mathbf{b})+\mathbf{c}$ Add ***a*** and ***b*** first, then add ***c*** to the resultant

Vector addition is said to be associative because

$$\mathbf{a}+(\mathbf{b}+\mathbf{c})=(\mathbf{a}+\mathbf{b})+\mathbf{c} \qquad \text{—— (2)}$$

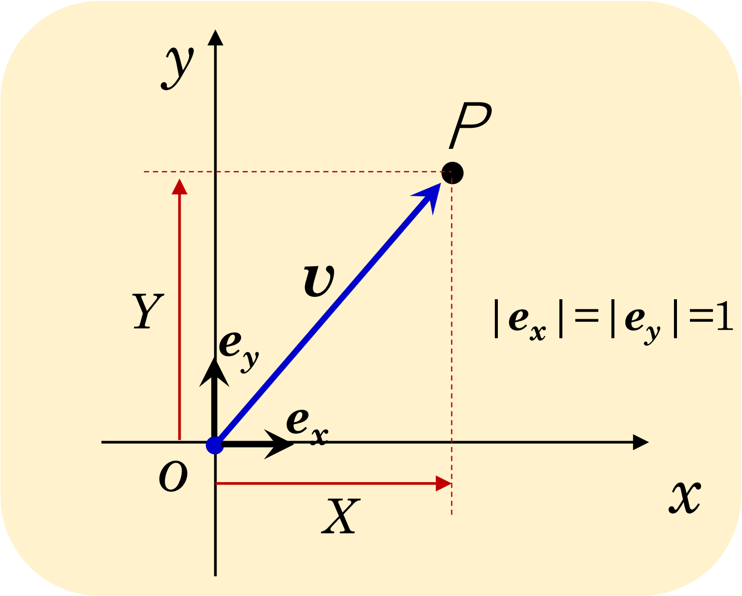
always holds true. The sum of three vectors may be written simply as

$$\mathbf{a}+\mathbf{b}+\mathbf{c}.$$

Exercise 1:
Verify eq.(2) graphically. (Draw vectors a, b and c, and show that the sums on the left- and the right-hand-side of eq.(2) result in an identical vector.)

Vector Components

2D Space with o-xy Cartesian Coordinate



Arbitrary Point $\longleftrightarrow$ Coordinates

P **One-to-one correspondence** (X, Y)

Vector
$\boldsymbol{v}$

We often abuse equality sign "=", and write the correspondences as

$$P=(X, Y), \quad \boldsymbol{v}=\underbrace{(X, Y)}_{\text{Vector components}}$$

The rigorous statement is

$$\boldsymbol{v}= X\boldsymbol{e}_x + Y\boldsymbol{e}_y$$

where $\boldsymbol{e}_x$ and $\boldsymbol{e}_y$ are horizontal and vertical unit vectors, respectively.

Component-wise Vector Addition

Decomposition of a vector into its components are particularly useful when working out vector algebra.

<u>Example</u>

To work out a vector sum $\boldsymbol{v}_1+\boldsymbol{v}_2$, we may first decompose vectors into component as

$$\boldsymbol{v}_1 = X_1\boldsymbol{e_x} + Y_1\boldsymbol{e_y}$$

$$\boldsymbol{v}_2 = X_2\boldsymbol{e_x} + Y_2\boldsymbol{e_y}$$

then add them component by component (component-wise vector addition).

$$\begin{aligned}\boldsymbol{v}_1 + \boldsymbol{v}_2 &= (X_1\boldsymbol{e_x} + Y_1\boldsymbol{e_y}) + (X_2\boldsymbol{e_x} + Y_2\boldsymbol{e_y}) \\ &= (X_1\boldsymbol{e_x} + X_2\boldsymbol{e_x}) + (Y_1\boldsymbol{e_y} + Y_2\boldsymbol{e_y}) \\ &= (X_1 + X_2)\boldsymbol{e_x} + (Y_1 + Y_2)\,\boldsymbol{e_y}\end{aligned}$$

Commutativity and associativity

Addition of collinear vectors

If the shorthand notation is employed, the process of component-wise vector addition may be written as below.

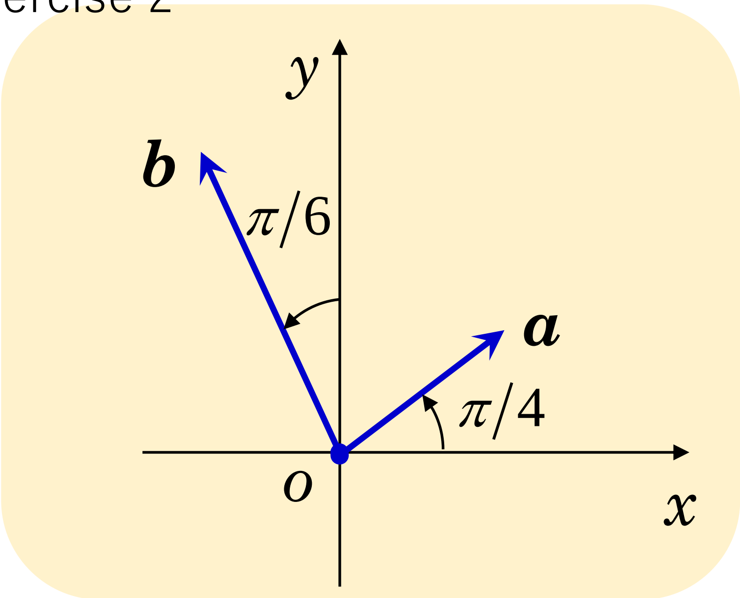
$$\boldsymbol{v}_1 = (X_1, Y_1)$$

$$\boldsymbol{v}_2 = (X_2, Y_2)$$

$$\begin{aligned}&\boldsymbol{v}_1 + \boldsymbol{v}_2 \\ &= (X_1, Y_1) + (X_2, Y_2) \\ &= (X_1 + X_2, Y_1 + Y_2)\end{aligned}$$

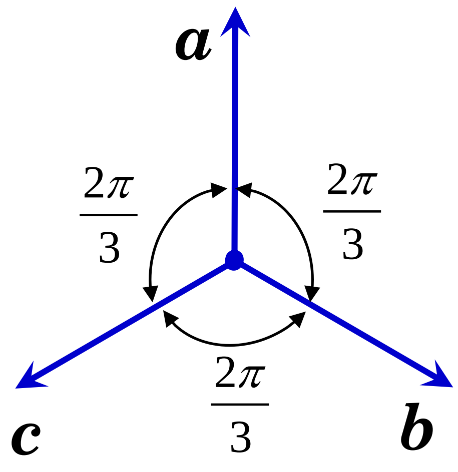
Exercises

Exercise 2



For the vectors $\boldsymbol{a}$ and $\boldsymbol{b}$ shown above, work out $\boldsymbol{a}+\boldsymbol{b}$ by a component-based method when $|\boldsymbol{a}|=1$ and $|\boldsymbol{b}|=2$, then obtain $|\boldsymbol{a}+\boldsymbol{b}|$.

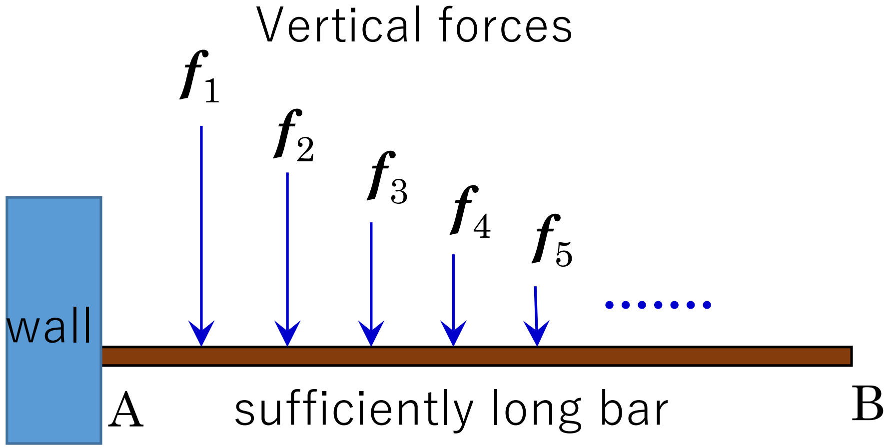
Exercise 3



Prove that $\boldsymbol{a}+\boldsymbol{b}+\boldsymbol{c}=\boldsymbol{0}$ if $|\boldsymbol{a}|=|\boldsymbol{b}|=|\boldsymbol{c}|$ by component-based vector addition method.

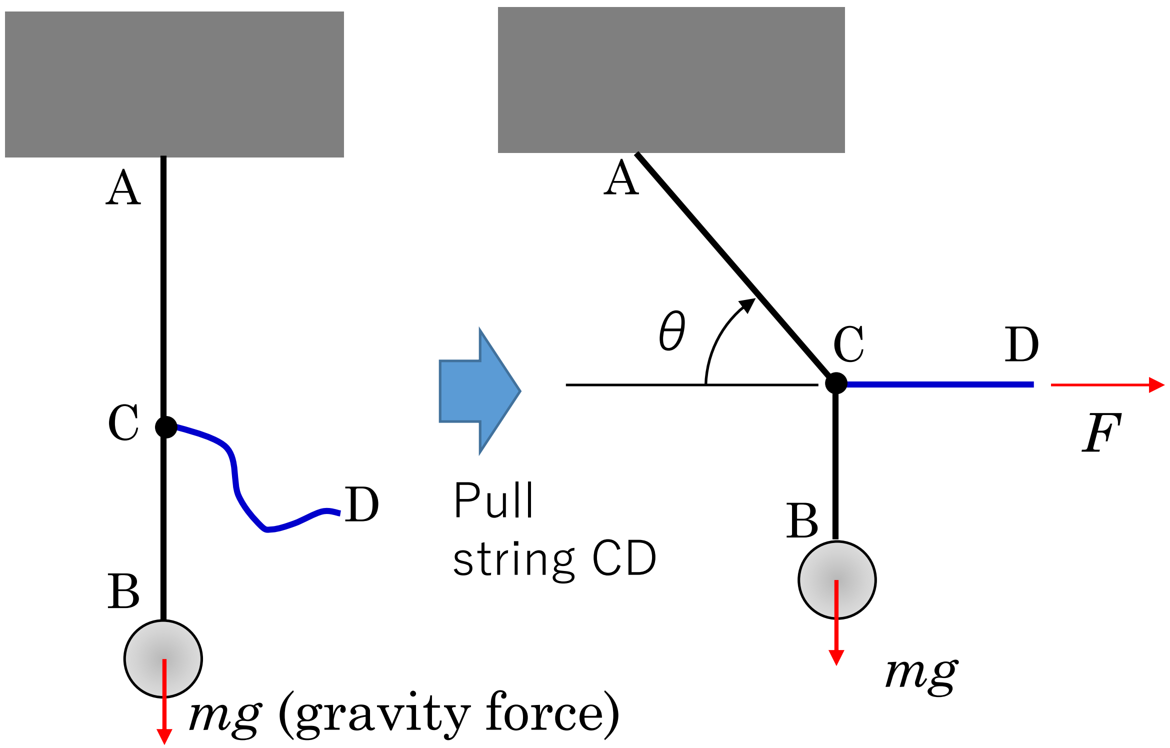
Exercises

Exercise 4



Suppose that a perfectly rigid bar AB is supported horizontally by a wall, and is subjected to infinitely many vertical forces $\boldsymbol{f}_i$ (i=1,2,...) whose magnitude decreases monotonically as $|\boldsymbol{f}_{i+1}|/|\boldsymbol{f}_i|=9/10$. Determine the direction and the magnitude of the total force acting to the bar.

Exercise 5



Suppose that an iron weight is hung from a ceiling by a string AB (see left figure). Determine the magnitude of the horizontal force F required to hold the weight as shown in the right figure. Note that m is mass and g is gravity constant.