

## **C. Fundamentals of Pharmaceutical Sciences**

### **C1. Physical Properties of Substances**

**GIO: To acquire knowledge of basic atomic/molecular structure, thermodynamics, and reaction kinetics to understand the physicochemical properties of substances.**

#### **(1) Structures of Substances**

**GIO: To acquire the fundamentals of atomic/molecular structures and the formation of chemical bonds.**

##### **① Chemical Bonds**

1. To describe the modes of chemical bonding.
2. To describe the fundamental concepts of molecular orbitals and orbital hybridization.
3. To describe the concepts of conjugation and resonance.

##### **② Intermolecular Interactions**

1. To describe van der Waals force.
2. To describe electrostatic interactions and to give specific examples.
3. To describe dipole-dipole interactions and to give specific examples.
4. To describe dispersion forces and to give specific examples.
5. To describe hydrogen bond formation and to give specific examples.
6. To describe charge-transfer interactions and to give specific examples.
7. To describe hydrophobic interactions and to give specific examples.

##### **③ Behavior of Atoms and Molecules**

1. To describe the properties of electromagnetic waves and their interaction with substances.
2. To describe molecular vibration, rotation, and electronic transition.
3. To describe electronic and nuclear spins and their magnetic resonance.
4. To describe refraction, polarization, and optical rotation of light.
5. To describe light scattering and interference.
6. To describe the basics of crystal structures and diffraction phenomena.

##### **④ Radiation and Radioactivity**

1. To describe the structures of atoms and radioactive disintegration.
2. To list the types of ionizing radiation and describe their properties and interactions with substances.
3. To describe the physical properties of typical radionuclides.
4. To describe nuclear reactions and radioactive equilibrium.
5. To describe the basic principles and use of radiation measurements.

#### **(2) Energy of Substances and Equilibrium States**

**GIO: To acquire the fundamentals of thermodynamics to understand substance states.**

##### **① Gas-Phase Microstates and Macrostates**

1. To describe the Van der Waals equation of state.
2. To describe the relationship between molecular movement and the energy of gases.

3. To describe energy quantization and the Boltzmann distribution.

## ② Energy

1. To describe systems, surroundings, and boundaries in thermodynamics.
2. To describe the first law of thermodynamics.
3. To describe the difference between state function and path function.
4. To describe isobaric, isovolumetric, isothermal, and adiabatic processes.
5. To describe heat capacities at constant volume and pressure.
6. To describe enthalpy.
7. To describe enthalpy changes in chemical reactions.

## ③ Spontaneous Change

1. To describe entropy.
2. To describe the second law of thermodynamics.
3. To describe the third law of thermodynamics.
4. To describe Gibbs energy.
5. To predict the direction and degree of spontaneous change using thermodynamic functions.

## ④ Principles of Chemical Equilibrium

1. To describe the relationship between Gibbs energy and chemical potential.
2. To describe the relationship between Gibbs energy and equilibrium constants.
3. To describe the effects of pressure and temperature on equilibrium constants.
4. To describe the principles of coupled reactions.

## ⑤ Phase Equilibrium

1. To describe heat transfer associated with phase changes.
2. To describe phase equilibrium and the phase rule.
3. To describe phase diagrams.

## ⑥ Solution Properties

1. To describe the colligative properties of dilute solutions.
2. To describe activity and activity coefficients.
3. To describe the concentration-dependent changes in the electric conductivity and molar conductivity of electrolyte solutions.
4. To describe ionic strength.

## ⑦ Electrochemistry

1. To describe the relationship between electromotive force and Gibbs energy.
2. To describe electrode potential (oxidation-reduction potential).

### **(3) Kinetic Properties of Chemical Reactions**

**GIO: To acquire the fundamentals of reaction kinetics to understand the conversion processes of substances.**

#### **① Reaction Rates**

1. To describe reaction orders and rate constants.
2. To convert differential rate equations to integral rate equations.
3. To describe the typical methods determining reaction order.
4. To measure the reaction rates of typical (pseudo-)first-order reactions and calculate the rate constants.
5. To describe the characteristics of typical compound complex reactions (reversible, parallel, and consecutive reactions, etc.).
6. To describe the relationship between reaction rate and temperature.
7. To describe typical catalytic reactions (acid/base catalytic reactions, enzymatic reactions, etc.).

### **C2. Analysis of Chemical Substances**

**GIO: To acquire the fundamentals of qualitative and quantitative analyses to analyze chemical substances (including drugs) accurately.**

#### **(1) Fundamentals of Analytical Methodology**

**GIO: To acquire the fundamentals of the use of analytical instruments and the use of analytical data.**

##### **① Fundamentals of Analysis**

1. To use analytical instruments appropriately.
2. To treat analytical data appropriately.
3. To describe method validation procedures.

#### **(2) Chemical Equilibria in Solutions**

**GIO: To acquire the fundamentals of various types of chemical equilibria in solutions.**

##### **① Acid-Base Equilibrium**

1. To describe the theory of acid-base equilibrium.
2. To describe pH and dissociation constants.
3. To measure the pH of solutions.
4. To describe buffer actions and specific buffers.

##### **② Other Types of Chemical Equilibria**

1. To describe complex/chelate formation equilibrium.
2. To describe precipitation equilibrium.
3. To describe oxidation-reduction equilibrium.
4. To describe partition equilibrium.

### **(3) Qualitative and Quantitative Analyses of Chemical Substances**

**GIO: To acquire the fundamentals of qualitative and quantitative analyses of chemical substances.**

#### **① Qualitative Analysis**

1. To describe the qualitative reactions of typical inorganic ions.
2. To list and describe the identification tests of the typical drugs listed in the Japanese Pharmacopoeia.

#### **② Quantitative Analysis (Volumetric and Gravimetric Analyses)**

1. To describe the principles, procedures, and applications of neutralization titration (including nonaqueous titration).
2. To describe the principles, operating procedures, and applications of chelatometric titration.
3. To describe the principles, operating procedures, and applications of precipitation titration.
4. To describe the principles, operating procedures, and applications of oxidation-reduction titration.
5. To perform volumetric analysis of typical drugs listed in the Japanese Pharmacopoeia.
6. To list and describe the purity tests included in the Japanese Pharmacopoeia.
7. To describe the principles and procedures of gravimetric analyses included in the Japanese Pharmacopoeia.

### **(4) Instrumental Analysis**

**GIO: To acquire the fundamentals of the principles and applications of instrumental analysis.**

#### **① Spectroscopic Analysis**

1. To describe the principles and applications of ultraviolet-visible absorption spectrophotometry.
2. To describe the principles and applications of fluorometry.
3. To describe the principles and applications of infrared (IR) absorption spectrophotometry.
4. To describe the principles and applications of atomic absorption spectrophotometry, inductivity coupled plasma (ICP) emission spectrometry, and ICP mass spectrometry.
5. To describe the principles and applications of polarimetry (including optical rotatory dispersion).
6. To analyze typical drugs included in the Japanese Pharmacopoeia using spectroscopic methods.

#### **② Nuclear Magnetic Resonance Spectroscopy**

1. To describe the principles and applications of nuclear magnetic resonance (NMR) spectroscopy.

#### **③ Mass Spectrometry**

1. To describe the principles and applications of mass spectrometry.

#### **④ X-ray Analysis**

1. To describe the principles and applications of X-ray crystallography.
2. To describe the principles and uses of the X-ray powder diffraction method.

#### **⑤ Thermal Analysis**

1. To describe the principles of thermogravimetry.
2. To describe differential thermal analysis and differential scanning calorimetry.

## **(5) Separation Analysis**

**GIO: To acquire the fundamentals of separation analysis.**

### **① Chromatography**

1. To describe separation mechanisms in chromatography.
2. To describe the characteristics and typical detection methods of thin-layer chromatography.
3. To describe the characteristics and typical detection methods of liquid chromatography.
4. To describe the characteristics and typical detection methods of gas chromatography.
5. To identify and determine samples using chromatography.

### **② Electrophoresis**

1. To describe the principles and applications of electrophoresis.

## **(6) Techniques for Biomedical Analysis**

**GIO: To acquire the fundamentals of typical analytical techniques used in clinical practice.**

### **① Preparation for Analysis**

1. To describe pretreatment methods appropriate for the biomedical analysis.
2. To describe the significance of quality control and standard reference materials in biomedical analysis.

### **② Analytical Techniques**

1. To list typical analytical methods used in biomedical analysis.
2. To describe the principles of immunochemical assays.
3. To describe the principles of typical analytical methods using enzymes.
4. To describe typical dry chemistry methods.
5. To describe typical diagnostic imaging techniques (X-ray examination, magnetic resonance imaging (MRI), ultrasound, endoscopy, nuclear medicine examination, etc.).

## **C3. Properties and Reactions of Chemical Substances**

**GIO: To acquire the fundamentals of the structures, properties, reactions, separation methods, and structural determination methods of typical organic compounds as well as the structures and properties of typical inorganic compounds to understand chemical substances.**

### **(1) Fundamental Properties of Chemical Substances**

**GIO: To acquire the fundamentals of the nomenclature, electronic configurations, types and processes of reactions, and stereostructures of basic organic compounds.**

#### **① Fundamentals**

1. To name typical compounds according to the IUPAC rules.
2. To describe typical compounds used in pharmacy using their common names.
3. To draw basic compounds using Lewis structures.
4. To describe the relationship between the properties and resonance of organic compounds.
5. To define Lewis acids and bases as well as Brønsted acids and bases.

6. To understand the characteristics of basic organic reactions (substitution, addition, and elimination) and to classify them.
7. To describe the structures and properties of reaction intermediates containing carbon atoms (carbocations, carbanions, and radicals).
8. To describe the processes of reactions using energy diagrams.
9. To describe basic organic reaction mechanisms using curved arrows indicating the motion of electrons.

## ② Three-Dimensional Structures of Organic Compounds

1. To describe the difference between structural isomers and stereoisomers.
2. To describe the relationship between chirality and optical activity.
3. To describe enantiomers and diastereomers.
4. To describe racemic and meso compounds.
5. To describe the notations for absolute configurations and to draw the structures of chiral compounds.
6. To describe the stereoisomerism of carbon-carbon double bonds (*cis-trans* and *E-Z* isomerism).
7. To draw the structures of organic compounds using Fischer and Newman projections.
8. To describe the conformations of ethane and butane and their stability.

## (2) Structures and Reactions of Basic Organic Compounds

**GIO: To acquire the fundamentals of the structures, properties, and reactivity of aliphatic and aromatic compounds.**

### ① Alkanes

1. To describe the basic properties of alkanes.
2. To illustrate the structural isomers of alkanes.
3. To describe the factors determining ring strain in cycloalkanes.
4. To illustrate the carbon-hydrogen bond directions (axial and equatorial) in the chair conformations of cyclohexanes.
5. To describe the factors determining the stable conformations of substituted cyclohexanes.

### ② Alkenes and Alkynes

1. To list the typical addition reactions to alkenes and describe their characteristics.
2. To list the typical oxidation and reduction reactions of alkenes and describe their characteristics.
3. To list the typical reactions of alkynes and describe their characteristics.

### ③ Aromatic Compounds

1. To describe the properties and reactivity of typical aromatic hydrocarbon compounds.
2. To describe the concept of aromaticity.
3. To describe the effects of substituents on the reactivity and orientation in the electrophilic substitution reactions of aromatic hydrocarbons.
4. To describe the properties of typical aromatic heterocycles in relation to aromaticity.
5. To describe the effects of substituents on the reactivity and orientation in the electrophilic substitution reactions of typical aromatic heterocycles.

### **(3) Properties and Reactions of Functional Groups**

**GIO: To acquire the fundamentals of the properties and reactivity of organic compounds containing functional groups.**

#### **① Overview**

1. To list typical functional groups and describe their properties.
2. To conduct isolation and purification procedures based on the properties of functional groups.

#### **② Organohalogen Compounds**

1. To list and describe the basic properties and reactions of organohalogen compounds.
2. To describe the characteristics of nucleophilic substitution reactions.
3. To describe the characteristics of elimination reactions.

#### **③ Alcohols, Phenols, and Ethers**

1. To list and describe the basic properties and reactions of alcohols and phenols.
2. To list and describe the basic properties and reactions of ethers.

#### **④ Aldehydes, Ketones, Carboxylic Acids, and Carboxylic Acid Derivatives**

1. To list and describe the basic properties and reactions of aldehydes and ketones.
2. To list and describe the basic properties and reactions of carboxylic acids.
3. To list and describe the basic properties and reactions of carboxylic acid derivatives (acid halides, acid anhydrides, esters, and amides).

#### **⑤ Amines**

1. To list and describe the basic properties and reactions of amines.

#### **⑥ Electronic Effects**

1. To describe the electronic effects of functional groups.

#### **⑦ Acidity and Basicity**

1. To compare and describe the acidity of alcohols, phenols, carboxylic acids, and carbon acids.
2. To compare and describe the basicity of nitrogen-containing compounds.

### **(4) Structural Determination of Chemical Substances**

**GIO: To acquire the fundamentals of structural determination methods using typical instrumental analyses including nuclear magnetic resonance (NMR), infrared absorption (IR), and mass spectrometry (MS).**

#### **① Nuclear Magnetic Resonance**

1. To describe briefly the information obtained from  $^1\text{H}$  and  $^{13}\text{C}$  NMR spectra.
2. To identify the approximate chemical shifts of typical protons in organic compounds.
3. To describe the meaning of the integration of  $^1\text{H}$  NMR spectra.
4. To describe the basic modes of splitting where  $^1\text{H}$  NMR signals are split by adjacent protons (coupling).
5. To determine the substructures of typical compounds based on  $^1\text{H}$  NMR spectra.

## ② Infrared Absorption

1. To describe briefly the information obtained from IR spectra.
2. To describe the characteristic IR spectral absorptions of basic functional groups and assign them.

## ③ Mass Spectrometry

1. To describe briefly the information obtained from mass spectra.
2. To choose appropriate ionization methods based on the properties of compounds.
3. To describe the types of peaks (base peaks, molecular ion peaks, isotopic peak, and fragment peaks) obtained in IR spectra.
4. To analyze the mass spectra of typical compounds.

## ④ Comprehensive Practice

1. To determine the structures of typical compounds using common instrumental analytical methods.

## (5) Structures and Properties of Inorganic Compounds and Complexes

**GIO: To acquire the fundamentals of the structures and characteristics of typical inorganic compounds and complexes (including drugs).**

### ① Inorganic Compounds and Complexes

1. To list main group elements and transition elements.
2. To list the names, structures, and properties of typical inorganic oxides and oxo compounds.
3. To list the names, structures, and properties of reactive oxygen species and nitrogen oxides.
4. To describe the names, structures, and basic properties of typical complexes.
5. To list typical inorganic compounds and complexes used as drugs.

## C4. Chemistry of Biomolecules and Drugs

**GIO: To acquire the fundamentals of the structures and characteristics of drug targets and drugs, and the chemistry of biological reactions to understand the biological effects of drugs from the viewpoint of chemistry.**

### (1) Structures and Chemical Properties of Target Molecules

**GIO: To acquire the fundamentals of the basic structures and chemical properties of target molecules.**

#### ① Chemical Structures of Target Molecules

1. To describe the chemical properties of molecules (amino acids, sugars, lipids, nucleotides, etc.) constituting typical biopolymers based on their structures.
2. To describe the three-dimensional structures of biopolymers (proteins, nucleic acids, etc.) and the chemical bonds and interactions that determine them.

#### ② Small Organic Compounds in the Human Body

1. To describe the structures and characteristics of typical endogenous ligands for cell membrane receptors and intracellular (nuclear) receptors.



2. To describe the roles of typical coenzymes in enzymatic reactions from the aspects of organic reaction mechanisms.
3. To describe the biological reactions using reactive oxygen species and nitric oxide from the viewpoint of structural chemistry.
4. To describe the chemical roles of typical metal ions and complexes present in the human body from the viewpoint of chemistry.

## **(2) Chemistry of Biological Reactions**

**GIO: To acquire the fundamentals of biological reactions determining the activities of drugs.**

### **① Phosphorus and Sulfur Compounds in the Human Body**

1. To describe the structures and chemical properties of phosphorus compounds (phosphorus acid and its derivatives, etc.), and sulfur compounds (thiols, disulfides, thioesters, etc.).
2. To describe the biological functions of phosphorus compounds (phosphorus acid and its derivatives, etc.) and sulfur compounds (thiols, disulfides, thioesters, etc.) based on their chemical properties.

### **② Enzyme Inhibitors and Their Modes of Action**

1. To describe the actions of irreversible enzyme inhibitors based on the reaction mechanisms of enzymes.
2. To describe how substrate analogues act as competitive inhibitors based on the reaction mechanisms of enzymes.
3. To describe how transition state analogues act as competitive inhibitors based on the reaction mechanisms of enzymes.

### **③ Receptor Agonists and Antagonists**

1. To describe the differences between typical receptor agonists and antagonists by comparing their structures with those of endogenous ligands.
2. To explain why low-molecular endogenous ligand derivatives are often used as drugs.

### **④ Organic Reactions in the Human Body**

1. To describe the metabolic reactions of typical biological molecules (fatty acids and cholesterol, etc.) from the viewpoint of organic chemistry.
2. To describe xenobiotic metabolic reactions (e.g., metabolic activation of carcinogens) from the viewpoint of organic chemistry.

## **(3) Structures, Properties, and Actions of Drugs**

**GIO: To acquire the fundamentals that relate typical structures and properties of drugs affecting their actions.**

### **① Interactions Between Drugs and Biomolecules**

1. To describe the interactions between drugs and biomolecules from the viewpoint of chemistry (binding affinity and free-energy change, electronic effects, steric effects, etc.).

**② Properties of Drugs Based on Their Chemical Structures**

1. To describe the physicochemical properties (acidity, basicity, hydrophobicity, hydrophilicity, etc.) of drugs based on their structures.
2. To describe the chemical structures of drugs, such as prodrugs, based on pharmacokinetics.

**③ Components of Drugs**

1. To describe the pharmacophores of typical drugs.
2. To describe bioisosteres giving typical examples.
3. To classify typical heterocycles in drugs based on their structures and to describe their properties as drug components.

**④ Structures and Properties of Drugs Acting on Enzymes**

1. To list typical drugs with nucleoside and nucleobase analogues and to describe their properties based on their chemical structures.
2. To list typical drugs with phenylacetate or phenylpropionate structures and to describe their properties based on their chemical structures.
3. To list typical drugs with sulfonamide structures and to describe their properties based on their chemical structures.
4. To list typical drugs with quinolone skeletons and to describe their properties based on their chemical structures.
5. To list typical drugs with beta-lactam structures and to describe their properties based on their chemical structures.
6. To list typical peptide analogue drugs and to describe their properties based on their chemical structures.

**⑤ Structures and Properties of Drugs Interacting with Receptors**

1. To list typical drugs with catecholamine skeletons and to describe their properties based on their chemical structures.
2. To list typical acetylcholine analogue drugs and to describe their properties based on their chemical structures.
3. To list typical steroid analog drugs and to describe their properties based on their chemical structures.
4. To list typical drugs that have benzodiazepine and barbital skeletons and to describe their properties based on their chemical structures.
5. To list typical opioid analogue drugs and to describe their properties based on their chemical structures.

**⑥ Structures and Properties of Drugs Acting on DNA**

1. To list DNA binding drugs (alkylating agents and cisplatin) and to describe their chemical structures and reaction mechanisms.
2. To list DNA intercalating drugs and to describe their structural characteristics.
3. To list DNA-strands breaking drugs and to describe their structural characteristics.

## ⑦ Structures and Properties of Drugs Interacting with Ion Channels

1. To describe the properties of typical structures of basic drugs interacting with ion channels (e.g., dihydropyridines).

## C5. Pharmacognosy (Naturally Derived Drugs)

**GIO: To acquire the fundamentals of the sources, properties, and clinical applications of typical crude drugs, and the isolation, structures, physical properties, and actions of natural bioactive substances to used natural substances as drugs.**

### (1) Plant, Animal, and Mineral Sources of Drugs

**GIO: To acquire the fundamentals of sources, description, constituents, and quality evaluation of plant-, animal-, and mineral-derived drugs.**

#### ① Medicinal Plants

1. To list the scientific names, medicinal parts, and medicinal effects of typical medicinal plants.
2. To describe and identify typical medicinal plants based on their external morphologies.
3. To describe the major internal morphologies of medicinal plants.
4. To describe the characteristics of plants for which handling is legally regulated (cannabises and poppies).

#### ② Sources of Crude Drugs

1. To list typical crude drugs (derived from plants, animals, algae, and fungi) included in the Japanese Pharmacopoeia and to describe their sources and medicinal parts.

#### ③ Uses of Crude Drugs

1. To describe the medicinal effects, constituents, and uses of typical crude drugs (derived from plants, animals, algae, fungi, and minerals) included in the Japanese Pharmacopoeia.
2. To list and describe typical crude drugs that may cause side effects and require caution when used.

#### ④ Identification and Quality Evaluation of Crude Drugs

1. To describe the methods of identification and quality evaluation of crude drugs.
2. To describe the general rules for and testing of crude drugs in the Japanese Pharmacopoeia.
3. To discriminate typical crude drugs.
4. To describe the identification tests for typical crude drugs.
5. To describe the purity tests for typical crude drugs.

### (2) Natural Products and Their Derivatives as Drug Sources

**GIO: To classify and organize natural bioactive substances as drug sources based on their structures and to acquire the fundamentals of their uses.**

#### ① Structures and Activities of Bioactive Substances Derived from Crude Drugs

1. To classify typical bioactive substances derived from crude drugs based on their chemical structures and to describe briefly their biosynthetic pathways.

2. To list typical bioactive substances derived from crude drugs which are classified as lipids or carbohydrates and describe their activities.
3. To list typical bioactive substances derived from crude drugs which are classified as aromatic compounds and describe their activities.
4. To list typical bioactive substances derived from crude drugs which are classified as terpenoids or steroids and describe their activities.
5. To list typical bioactive substances derived from crude drugs which are classified as alkaloids and describe their activities.

## ② Structures and Activities of Bioactive Substances Derived from Microorganisms

1. To classify bioactive substances derived from microorganisms based on their chemical structures.
2. To list typical bioactive substances derived from microorganisms and describe their activities.

## ③ Handling of Natural Bioactive Substances

1. To describe and perform typical methods of extraction and isolation/purification of natural bioactive substances.

## ④ Uses of Natural Bioactive Substances

1. To list common natural bioactive substances used as drugs and describe their uses.
2. To list common drugs developed through chemical modification of natural bioactive substances and describe their uses and lead compounds.
3. To list common natural bioactive substances used as pesticides or cosmetics and describe their uses.

# C6. Fundamentals of Biochemistry

**GIO: To acquire the fundamentals of the structures of cells and biomolecules to ensure understanding of organisms biochemically at the cellular and molecular levels.**

## (1) Structures and Functions of Cells

**GIO: To acquire the fundamentals of the structures and functions of cell membranes, organelles, and cytoskeletons.**

### ① Cell Membranes

1. To list common biological materials that constitute cell membranes and describe their functions at the molecular level.
2. To describe endocytosis and exocytosis.

### ② Organelles

1. To describe the structures and functions of organelles (nuclei, mitochondria, endoplasmic reticula, lysosomes, Golgi apparatus, peroxisomes, etc.) and ribosomes.

### ③ Cytoskeletons

1. To describe the structures and functions of cytoskeletons.

## **(2) Fundamentals of Biomolecules**

**GIO: To acquire the fundamentals of the structures, characteristics, and roles of biomolecules.**

### **① Lipids**

1. To describe the types, structures, characteristics, and roles of common lipids.

### **② Carbohydrates**

1. To describe the types, structures, characteristics, and roles of common monosaccharides and disaccharides.
2. To describe the types, structures, characteristics, and roles of common polysaccharides.

### **③ Amino Acids**

1. To list amino acids and to describe their characteristics based on their structures.

### **④ Proteins**

1. To describe the structures (primary, secondary, tertiary, and quaternary structures) and characteristics of proteins.

### **⑤ Nucleotides and Nucleic Acids**

1. To describe the types, structures, and characteristics of nucleotides and nucleic acids (DNA and RNA).

### **⑥ Vitamins**

1. To describe the types, structures, characteristics, and roles of common vitamins.

### **⑦ Trace Elements**

1. To describe the types and roles of common essential trace elements.

### **⑧ Identification and Quantification of Biomolecules**

1. To conduct qualitative and quantitative tests of lipids, carbohydrates, amino acids, proteins, and nucleic acids.

## **(3) Proteins Responsible for Biological Functions**

**GIO: To acquire the fundamentals of the structures, characteristics, functions and metabolisms of proteins responsible for biological functions.**

### **① Structures and Functions of Proteins**

1. To describe the various functions of proteins (enzymes, receptors, signaling molecules, membrane transporters, carrier/transporter proteins, reserve proteins, structural proteins, adhesion proteins, defensive proteins, and regulatory proteins.)

### **② Maturation and Degradation of Proteins**

1. To describe the maturation process of proteins after translation (transport between organelles and post-translational modification).
2. To describe the intracellular degradation of proteins.

### **③ Enzymes**

1. To describe the characteristics and kinetics of enzymatic reactions.
2. To describe the roles of coenzymes and trace metals in enzymatic reactions.
3. To describe typical regulatory mechanisms of enzyme activity.

4. To determine and analyze enzyme kinetics.

#### **④ Nonenzyme Proteins**

1. To describe the types, structures, and functions of membrane transporters.
2. To describe the types, structures, and functions of plasma lipoproteins.

### **(4) Fundamentals of Genetics**

**GIO: To acquire the fundamentals of the replication and expression of genes and their regulation.**

#### **① Overview**

1. To describe the mechanisms of the storage and expression of genetic information.
2. To describe the definitions of DNA, genes, chromosomes, and genomes.

#### **② Molecules of the Substance for Genetic Information**

1. To describe the structures of chromosomes (nucleosomes, chromatins, centromeres, telomeres, etc.).
2. To describe the structures of genes (promoters, enhancers, exons, introns, etc.).
3. To describe the different types of RNA (hnRNA, mRNA, rRNA, tRNA, etc.) and their functions.

#### **③ Genome Replication**

1. To describe the process of DNA replication.

#### **④ Process and Regulation of Transcription and Translation**

1. To describe the process of transcription from DNA to RNA.
2. To describe epigenetic regulations of the transcriptional.
3. To describe transcriptional regulation by transcription factors.
4. To describe RNA processing (cap structures, splicing, snRNP, poly-A chains, etc.).
5. To describe the process of translation of RNA to proteins.

#### **⑤ Genome Mutation and Repair**

1. To describe DNA mutation and repair.

#### **⑥ Recombination of DNA**

1. To describe genetic engineering techniques (gene cloning, cDNA cloning, PCR, recombinant protein expression, etc.).
2. To describe genetically modified organisms (transgenic or knockout animals, cloned animals, and genetically modified plants).

### **(5) Fundamentals of Metabolism**

**GIO: To acquire the fundamentals of the production, storage, and use of bioenergy, and the metabolism of carbohydrates, lipids, proteins, and nucleic acids that are responsible for those functions.**

#### **① Overview**

1. To describe the general process of energy metabolism.

#### **② ATP Production and Carbohydrate Metabolism**

1. To describe the glycolytic pathway and lactic acid production.
2. To describe the citric acid cycle (tricarboxylic acid cycle [TCA] cycle).

3. To describe the electron transport chain (oxidative phosphorylation) and ATP synthase.
4. To describe glycogen metabolism.
5. To describe gluconeogenesis.

### **③ Lipid Metabolism**

1. To describe the biosynthesis and beta-oxidation of fatty acids.
2. To describe the biosynthesis and metabolism of cholesterol.

### **④ Starvation and Repletion**

1. To describe energy metabolism in the starvation state, e.g. the use of ketone bodies.
2. To describe the mechanisms of surplus energy storage.

### **⑤ Other Metabolic Pathways**

1. To describe the metabolism of carbon and nitrogen in amino acid molecules (e.g., the urea cycle).
2. To describe the biosynthesis and degradation of nucleotides.
3. To describe the pentose phosphate cycle.

## **(6) Intercellular Communication and Intracellular Signal Transduction**

**GIO: To acquire the fundamentals of the modes and roles of intercellular communication and intracellular signaling.**

### **① Overview**

1. To describe the modes of signaling in intercellular communication.

### **② Intracellular Signal Transduction**

1. To describe intracellular signaling via receptors containing cell membrane channels.
2. To describe intracellular signaling from cell membrane receptors via the G protein system.
3. To describe intracellular signaling via phosphorylation of cell membrane receptor proteins.
4. To describe the role of second messengers in intracellular signaling.
5. To describe intracellular signaling via intracellular (nuclear) receptors.

### **③ Intercellular Communication**

1. To describe intercellular adhesion structures and the types and characteristics of major cell adhesion molecules.
2. To describe the types and characteristics of major extracellular matrix proteins.

## **(7) Cell Cycle**

**GIO: To acquire the fundamentals of the cell cycle, cell division, and cell death.**

### **① Cell Division**

1. To describe the cell cycle and its regulatory mechanisms.
2. To describe the division of somatic and germ cells.

### **② Cell Death**

1. To describe cell death (apoptosis and necrosis).

### ③ Cancer Cells

1. To describe the difference between normal cells and cancer cells.
2. To describe the roles of oncogenes and tumor suppressor genes.

## **C7. Anatomy and Human Physiology**

**GIO: To acquire the fundamentals of the structure, functions, and regulation of the human body for an understanding of anatomy at the overall physical, organ, and cellular levels.**

### **(1) Fundamentals of Human Anatomy**

**GIO: To acquire the fundamentals of genetics, ontogeny, and the structures and functions of organs.**

#### ① Genetics

1. To describe genes and the mechanisms of heredity.
2. To describe genetic polymorphisms.
3. To describe common genetic disorders.

#### ② Ontogeny

1. To describe ontogenesis.
2. To describe the roles of stem cells and precursor cells in cellular differentiation.

#### ③ Overview of Organ Systems

1. To list the names, morphologies, locations, and functions of the organs and organ systems constituting in the human body.
2. To identify the names and locations of various organs, using laboratory animals, anatomical models of the human body, or simulators.
3. To observe tissues and cells of typical organs under the microscope.

#### ④ Nervous System

1. To describe the roles and functions of the central nervous system.
2. To describe the roles and functions of the peripheral nervous system (autonomic and somatic nervous systems).

#### ⑤ Skeletal and Muscular Systems

1. To list major bones and muscles.
2. To list the names of typical skeletal muscles and joints and identify their locations.

#### ⑥ Skin

1. To describe the roles and functions of the skin.

#### ⑦ Circulatory System

1. To describe the roles and functions of the cardiac system.
2. To describe the roles and functions of the vascular system.
3. To describe the roles and functions of the lymphatic system.

#### ⑧ Respiratory System

1. To describe the roles and functions of the lungs and bronchi.



### **⑨ Digestive System**

1. To describe the roles and functions of the digestive tracts (stomach, small intestine, and large intestine).
2. To describe the roles and functions of the liver, pancreas, and gallbladder.

### **⑩ Urinary System**

1. To describe the roles and functions of the urinary tract system.

### **⑪ Reproductive System**

1. To describe the roles and functions of the reproductive system.

### **⑫ Endocrine System**

1. To describe the roles and functions of the endocrine system.

### **⑬ Sensory Organs**

1. To describe the roles and functions of the sensory organs.

### **⑭ Blood and Hematopoietic System**

1. To describe the roles and functions of the blood and the hematopoietic system.

## **(2) Fundamentals of Human Physiology**

**GIO: To acquire the fundamentals of the types and mechanisms of action of common transmitters responsible for the information networks involved in homeostasis.**

### **① Regulatory Mechanisms Controlled by the Nervous System**

1. To describe the regulatory mechanisms for the excitation and conduction of nerve cells and synaptic transmission.
2. To list common neurotransmitters and to describe briefly their bioactivities and mechanisms of action.
3. To describe common examples of the regulatory mechanisms for homeostasis via the nervous and sensory systems.
4. To describe the regulatory mechanisms for muscle contraction by nerves.

### **② Regulatory Mechanisms Controlled by Hormones and the Endocrine System**

1. To list typical hormones and to describe briefly their production organs, bioactivities, and mechanisms of action.

### **③ Regulatory Mechanisms Controlled by Autacoids**

1. To list common autacoids and to describe briefly their bioactivities and mechanisms of action.

### **④ Regulatory Mechanisms Controlled by Cytokines and Growth Factors**

1. To list common cytokines and growth factors and to describe briefly their bioactivities and mechanisms of action.

### **⑤ Regulatory Mechanisms of Blood Pressure**

1. To describe the mechanisms regulating blood pressure.

### **⑥ Regulatory Mechanisms of Blood Glucose**

1. To describe the mechanisms regulating blood glucose levels.

### **⑦ Body Fluid Regulation**

1. To describe the mechanisms regulating body fluids.
2. To describe the mechanisms regulating urine production and urine volume.

### **⑧ Body Temperature Regulation**

1. To describe the mechanisms regulating body temperature.

### **⑨ Blood Coagulation and Fibrinolytic System**

1. To describe the mechanisms regulating blood coagulation and the fibrinolytic system.

### **⑩ Menstrual Cycle Regulation**

1. To describe the mechanisms regulating the menstrual cycle.

## **C8. Biological Defense Mechanisms and Microorganisms**

**GIO: To acquire the fundamentals of biological defense mechanisms through immune reactions, their failure, and common pathogenic microorganisms to understand the changes that occur when homeostasis is disrupted.**

### **(1) Fundamentals of Immunology**

**GIO: To acquire the fundamentals of immune responses as the primary biological defense system in the human body.**

#### **① Biological Defense**

1. To describe roles of physical, physiological, and chemical barriers and complements against pathogen invasion.
2. To describe the features of immune reactions (self/non-recognition, specificity, diversity, clonality, memory, and tolerance).
3. To describe natural immunity, acquired immunity, and their relationship.
4. To describe humoral and cell-mediated immunity.

#### **② Immunocompetent Tissues and Cells**

1. To list the tissues involved in immunity and describe their roles.
2. To describe the types and roles of immunocompetent cells.
3. To describe the major intercellular networks in immune reactions.

#### **③ Molecular Mechanisms of Immunity**

1. To compare and describe the recognition of invasive pathogens in innate immunity and adaptive immunity.
2. To describe the structures and functions of major histocompatibility complex (MHC) antigens and their roles in antigen presentation.
3. To describe the diversity of antigen recognition (gene rearrangement) by T and B cells and their activation.
4. To describe the basic structures, types, and roles of antibody molecules.
5. To list major cytokines involved in the immune system and to briefly describe their activities.

## **(2) Fundamentals of the Human Immune Response**

**GIO: To acquire the fundamentals of the regulation and failure of immune responses and clinical applications of immune reactions.**

### **① Regulation and Failure of Immune Responses**

1. To describe the common symptoms of, cells responsible for, and reaction mechanisms of inflammation.
2. To classify allergies and to describe the cell responsible and reaction mechanisms.
3. To describe autoimmune diseases and immunodeficiency syndromes.
4. To describe the relationship between organ transplantation and immune reactions (rejection, immunosuppressants, etc.).
5. To describe the relationship between infections and immune responses.
6. To describe the immune reactions involved in tumor elimination and suppression.

### **② Application of Immune Reactions**

1. To describe the principles and types of vaccines (live vaccines, inactivated vaccines, toxoids, combination vaccines, etc.).
2. To describe monoclonal and polyclonal antibodies.
3. To describe serotherapy and antibody drugs.
4. To perform tests based on antigen-antibody reactions (ELISA, Western blotting, etc.).

## **(3) Fundamentals of Microbiology**

**GIO: To acquire the fundamentals of the classification, structures, and life cycles of microorganisms.**

### **① Overview**

1. To describe the characteristics of prokaryotes, eukaryotes, and viruses.

### **② Bacteria**

1. To describe the classification and characteristics of bacteria (phylogenetic classification, Gram-positive vs. Gram-negative bacteria, aerobic vs. anaerobic bacteria, etc.).
2. To describe the structures and proliferation mechanisms of bacteria.
3. To describe catabolism (respiration and fermentation) and anabolism in bacteria.
4. To describe gene transmission (conjugation, transduction, and transformation) in bacteria.
5. To describe drug-resistant bacteria and resistance acquisition mechanisms.
6. To describe common bacterial toxins.

### **③ Viruses**

1. To describe the structures, classifications, and proliferation mechanisms of viruses.

### **④ Fungi, Protozoans, and Helminths**

1. To describe the characteristics of fungi.
2. To describe the characteristics of protozoans and helminths.

### **⑤ Disinfection and Sterilization**

1. To describe the concepts of sterilization, disinfection and sanitization, and bacteriostasis.

2. To describe typical sterilization and disinfection methods.

#### ⑥ Detection Methods

1. To perform Gram staining.
2. To perform aseptic manipulation.
3. To perform the isolation and pure culture of common bacteria or fungi.

### (4) Human Pathogenic Microorganisms

**GIO: To acquire the fundamentals of human-microorganism relationships and pathogenic microorganisms.**

#### ① Establishment of Infection and Symbiosis

1. To describe the routes of infection (sources, pathways, portals of entry, etc.) and symbiosis, e.g., intestinal bacteria.
2. To describe opportunistic infection and hospital-acquired infections.

#### ② Typical Pathogens

1. To describe DNA viruses (human herpes viruses, adenoviruses, papillomaviruses, hepatitis B viruses, etc.).
2. To describe RNA viruses (noroviruses, rotaviruses, polioviruses, coxsackieviruses, echoviruses, rhinoviruses, hepatitis A viruses, hepatitis C viruses, influenza viruses, measles viruses, rubella viruses, Japanese encephalitis viruses, rabies viruses, mumps viruses, HIV, HTLV, etc.).
3. To describe Gram-positive cocci (*Staphylococcus* spp., *Streptococcus* spp., etc.) and Gram-positive bacilli (*Clostridium tetani*, *Clostridium perfringens*, *Clostridium botulinum*, *Corynebacterium diphtheriae*, *Bacillus anthracis*, *Bacillus cereus*, *Clostridium difficile*, etc.).
4. To describe Gram-negative cocci (*Neisseria gonorrhoeae*, *Neisseria meningitidis*, etc.) and Gram-negative bacilli (*Escherichia coli*, *Shigella* spp., *Salmonella* spp., *Salmonella enterica* serovar *Typhi*, *Yersinia* spp., *Klebsiella* spp., *Vibrio cholerae*, *Bordetella pertussis*, *Vibrio parahaemolyticus*, *Pseudomonas aeruginosa*, *Legionella* spp., *Haemophilus influenzae*, etc.).
5. To describe Gram-negative spirilla (*Helicobacter pylori*, *Campylobacter jejuni/coli*, etc.) and Spirochaeta.
6. To describe acid-fast bacilli (*Mycobacterium tuberculosis*, *Mycobacterium leprae*, etc.).
7. To describe *Mycoplasma*, *Rickettsia*, and *Chlamydia*.
8. To describe fungi (*Aspergillus* spp., *Cryptococcus* spp., *Candida* spp., *Mucor* spp., *Trichophyton* spp., etc.).
9. To describe protozoans (*Plasmodium* spp., *Toxoplasma gondii*, *Trichomonas vaginalis*, *Cryptosporidium* spp., *Entamoeba histolytica*, etc.) and helminths (*Ascaris* spp., *Trichuris* spp., *Anisakis* spp., *Echinococcus* spp., etc.).